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HIGH TEMPERATURE INVESTIGATION AND A STUDY OF METALLIC CONDUCTION.*

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I. TEMPERATURE A CONDITION OF MATTER.

THE temperature of a body is commonly estimated by touching it and finding if it feels hot, warm, or cold. But if the body glows its temperature is judged by the sense of sight, and the temperature is considered high in proportion to the brightness of the light which the body emits. Again, if a substance, ordinarily observed in its gaseous or liquid form, is seen in its solid form, and is recognized as the same substance, it is then called very cold and is said to be at a low temperature. All sense perceptions inform us that what we call temperature is a word which expresses our recognition of a *condition* under which all matter exists, and common experience shows that this condition varies widely.

Analysis informs us that the condition of matter called temperature is a species of motion, and that this motion is not an organized motion of the mass as a whole, but a disorganized motion of the minute, invisible parts of the body. As the senses give no account of absolute temperature, and only a rough estimate of relative temperatures, a scientific scale of absolute temperature based upon some physical principle, and realizable by observing

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the variation in some physical property of matter, is required for obtaining any precise quantitative observations. A scale of this character is provided in Lord Kelvin's thermodynamic scale, in which the temperature is defined as a quantity proportional to the mean kinetic energy per molecule of the molecules of a substance. If the molecules of the substance are absolutely at rest, the mean kinetic energy of any molecule is zero and the temperature is zero. A rise of temperature of a uniformly-heated portion of an ideal gas will be in direct proportion to the mean kinetic energy, or to the square of the mean velocity of its molecules. It is shown that when either the volume or pressure of the ideal gas is maintained constant the absolute temperature increases proportionally with an increase in the variable factor. This absolute scale of temperature, which is independent of the nature of any substance, starts with its zero 273° C. below the zero of the centigrade scale. When degrees are expressed in this scale they should be called, and now generally are, degrees Kelvin, in honor of the author of the scale. In temperature investigations we shall assume that a temperature is known precisely to just that extent to which it can be identified with, or can be expressed in terms of, this scale.

In actual observations of high temperature, the point is soon passed where the volume or pressure change in any actual gas can be observed and the true temperature be measured directly on the thermodynamic scale. The limit of the gas thermometer scale is about 1825° K., while it is assumed from various lines of evidence that not less than 4000° K. may be obtained in the laboratory. It follows that any measurement of temperature beyond the limits of the gas thermometer must be based upon the assumption that some property of matter continues to change above 1825° K. by some law of change deduced from observations made below this temperature where comparison with the gas scale is possible. The total radiation and the visible radiation emitted by matter give a valuable means of measuring high temperatures. Certain of the laws by which matter emits radiation rest upon a fairly secure theoretical basis. Since all kinds of matter, under conditions which are generally possible to realize, obey these laws in the same way, one is also justified in referring temperature to the radiation of matter and establishing an absolute scale of temperature upon properties of radiation obeyed alike by all kinds of matter. The connection between the thermodynamic scale and

the scales based upon the so-called radiation laws of Stefan-Boltzmann and Wien have been satisfactorily established as high as the melting-point of platinum. However, for these laws to hold, certain conditions (namely, those of black-body radiation) must be fulfilled, and, as these conditions cannot be fulfilled in studying the temperature of the sun, stars, and nebulæ, it is mere speculation to presume that the temperatures of these bodies can be measured. All that may be said regarding the temperature of these bodies is that they emit radiation which corresponds to the kind of radiation a black body would emit if it could be continually raised in temperature beyond anything ever observed and at the same time continue to radiate according to the same laws obeyed in the temperature range where observation is possible. From these considerations we shall assume that quantitative high temperature investigation ends where carbon—the most refractory of all known materials—vaporizes. If vastly higher temperatures are assumed by the astronomers to exist in the sun and stars, we must consider that their assertions refer only to the character of the radiation which they observe, and hence have no direct interest for investigators of terrestrial and realizable temperatures.

If matter with which we can experiment may be submitted to a temperature between 1° or 2° K. and 4000° K., a comprehensive physics of matter will consider and examine its properties as these are presented under all producible temperature conditions. It is a limited aspect of the science of physics to consider that its field is confined to a study of the properties of matter when found in the accidental and narrow range of temperature where life exists. Yet the physics of the past has given us the so-called laws of matter, energy, and electricity where these are considered as concepts of an objective reality that chances to exist between 273° and 373° K.—about 2½ per cent. of the temperature range obtainable. The physics of the present is a broader science, which is more and more recognizing both obligations and immense possibilities for the future. Its obligations are: to extend investigation of the phenomena of matter and the relations of matter to energy and electricity throughout the entire temperature range producible in the laboratory. Its possibilities are: the discovery of new forces, new relations and manifestations of the known forces, and of novel means of utilizing known and yet

undiscovered forces to useful ends. By passing to the limits in the study of such quantities as temperature, pressure, current density, magnetic density, rotational velocity, etc., the science of matter, energy, and electricity may hope to acquire the extended vision to which it is entitled, and to view these entities, not in the present restricted and transitory phase of their existence, but over a large extent of the phenomenal history through which they pass in their evolutionary development.

II. VARIATION OF THE PROPERTIES OF MATTER WITH TEMPERATURE.

Most of the properties exhibited by a body change when the conditions are changed under which the body exists. Inertia and weight, however, so far as at present investigated, are not altered by any change in conditions. Temperature is a unique condition in that it affects the properties of matter to a greater extent than any other change of condition to which matter may be subjected. The elements and the compounds of the elements, however, behave quite differently under wide temperature changes. In the case of the elements, though these exhibit widely different properties at different temperatures, when returned to a particular temperature, after having been carried through a wide temperature change, they are found to exhibit, with few unimportant exceptions, the same properties at the same temperature. Thus a non-metallic element, as oxygen, or a metallic element, as gold, exhibits exactly the same characteristic properties at 20° C. whether it has or has not previously been carried to temperatures which extend over the entire producible range. In other words, the chemical elements, in the main, give no evidence at any particular temperature of their previous physical history. Unimportant exceptions to this general statement exist, as shown by the different kinds of crystallization produced in an element by its past physical history. But if the particular temperature is chosen where the element is a fluid, gas, or vapor, then no evidence remains of its past temperature history. Compounds of the elements, on the other hand, show no abiding properties at a particular temperature except inertia and weight, provided they have been carried through temperature changes chosen sufficiently great. All give evidence by dehydration, by decomposition, by polymorphism, by crystallization, by chemical alteration, etc., of their previous temperature history. Thus, if a magnesium sili-

cate, as soapstone, had ever been taken, since its formation, to a temperature of 1000° C., evidence of this would be shown by the flinty hardness always acquired by this material when once subjected to high temperature. Many compounds, chiefly organic, are permanently and entirely altered when the temperature is raised only a few degrees, as when an egg is cooked. Other compounds, notably the oxides of the metals, as the oxides of magnesium, aluminum, etc., are so stable that they give evidence of their temperature history only after being submitted to the greatest extremes of temperature. It thus appears that a full interpretation and understanding of the compounds of the elements, as these are manifested at ordinary temperature, can only become possible by following experimentally the changes produced in the properties of these materials, transient and abiding, as they are submitted to temperatures which cover the entire range of temperature in which they can exist as identifiable materials. Such extended temperature investigations of the compounds of the elements are needed, not only for the better understanding of them at ordinary temperature, but also for the new facts and laws, of probable usefulness, which investigations at unusual temperatures are sure to reveal. Likewise, though to a less extent, the laws of the phenomena of the elements as revealed at ordinary temperature will receive much illumination from investigations of their properties throughout a greatly extended range of temperature, especially when the investigations are extended into the region of high temperature. Investigations made at high temperature are certain to disclose unsuspected properties possessed by the elements which will find important applications in science and the industries. Thus the writer's purely scientific investigation of the resistivity curve of molten tin proved that this material increases linearly with the temperature to at least 1680° C., and he has been able to utilize this heretofore unknown property of tin for all his measurements of high temperature to near 1700° C.

But there is another motive, the same which induces financiers to donate millions to astrophysical laboratories, for investigating the properties of matter over the entire range of temperature to which it may be submitted in the laboratory. This motive is the instinctive craving of the intellect to reproduce as completely and as truly as possible a mind replica of Nature. It is the in-

fluence of this motive which has produced the growth of the greater part of our present-day science, physical, chemical, and biological. In the past, however, the natural history, or physics and chemistry of matter, was studied in what may be termed the "life range" of temperature, say —40° to 100° C.—a mere 3½ per cent. of the temperature range in which the properties of matter may now be investigated.

The properties and phases of matter in this very restricted range are, nevertheless, of greater interest generally than at temperatures far removed from the life range, because the interests of human beings are chiefly associated with matter which exhibits the properties which it possesses at ordinary temperature. But by studying the properties of matter at high and low temperatures we shall come to a better understanding of it at the temperature where we come in contact with it and use it. The variety and complexity of the phenomena of matter revealed in a temperature range where there is crystallization and protoplasm and magnetism are far greater than in other temperature interval.

This circumstance, that more data are presented for observation, increases greatly the task of deducing laws and detecting governing principles; that is, mentally abstracting from a variety of phenomena elements which are common to and characteristic of many or all. The surprise is that, with the complexities encountered by the investigators of the past, we inherit as much coördinated truth and generalization as we do. A more searching method of attack is presented to our generation and those to come. This new method consists in the effort to interpret the phenomena manifested by matter in the particular phases which it exhibits in the life range of temperature, by taking the wide view of the properties of matter which is acquired by studying the phenomena which matter presents throughout the entire temperature range. The part is most correctly interpreted when studied in the light of the whole. To attempt an explanation of the physics and chemistry of matter by confining investigation to 3 or 4 per cent. of the temperature range in which matter might be studied is as if an art critic were to try and judge the beauty of Raphael's Sistine Madonna by inspecting one small area of the canvas through a pinhole in a card. The true significance and the beauty of any part selected for inspection may be recognized only when this part is seen from the proper standpoint in its

setting and relation to the entire creation. The broad view in science is not less important for the correct understanding of phenomena than in art for the full recognition of beauty.

If the complexity of Nature makes interpretation difficult in the life range of temperature, the technical difficulties, on the other hand, of experimental investigation at low and high temperatures become rapidly greater as investigation is extended in either of these directions.

It is probably due to this circumstance, in part at least, why our knowledge of Nature has been limited hitherto to a very short range of temperature. New inventions and modern methods of research, however, are rapidly removing these limitations. Hence the physicist of the future should have no reason or desire to confine either his investigations or his philosophic inquiries upon the nature and laws of matter, energy, and electricity within the narrow limits held to in the past. The diversity and the number of the problems presented are so vast, however, that the individual investigator desiring intellectual efficiency will select for study the modifications and manifestations of some particular phase or property of matter which abides when a body is carried to great extremes in the temperature range. Thus one might select for study the temperature history of the thermal conductance of one or more varieties of matter, or the vapor pressure, or the magnetic, gravitational, electrical, or molecular forces, or the spectral radiation of certain selected elements.

Of all the properties of matter most deserving investigation, one which is exhibited in all its conditions of temperature, and which has peculiar fascination, is the property possessed by matter of conducting or transporting electricity. We pass then to the particular topic of this paper.

III. THE PROBLEM OF ELECTRICAL CONDUCTION.

Two bodies, as a rod of glass and a piece of silk, ordinarily exhibit no properties at any temperature which we call electrical. Rub them together, then draw them apart. Each is found to be electrified, and in addition the space between them, even though the experiment is performed in a perfect vacuum, has acquired a peculiar condition. The common evidence of this peculiar condition acquired by the space between oppositely electrified bodies is given when any piece of matter which is electrically

conducting is held anywhere within the space between the electrified bodies, for it is found to assume an electrification and to exhibit polar properties. The particular point to note is that this peculiar condition of space by which it can electrify bodies held within it is not produced by the presence in the space itself of any material or substance to which can be assigned an objective independent existence. There need be no matter and no electricity in the space. Electricity, which we assume to be an independent entity consisting of extremely minute, discrete elements, called electrons, is located on and associated with the matter. The peculiar condition of the space between electrified bodies is called an electric stress, and is symbolically represented by lines of force which are contractile along their length and repellent normally to their direction. This stress is produced by a mysterious power which resides in the electricity. The electricity itself, however, resides on matter, and only its *influence* goes out of matter into space.

In electromagnetic radiation—as presented in wireless telegraphy and as ever present in the form of radiant heat and light—we observe a propagation of a *state or condition* produced in space by electricity—not a propagation of electricity itself.

Electrical conduction, or, perhaps, more properly stated, the transport of electricity from one point to another in space, is a process which involves (with a possible single exception of pure electronic conduction in high vacua) the transport of the matter itself to which the electricity is attached. The manner of transport of electricity through a metallic element from one point to another point in the metal constitutes the problem of metallic conduction. The manner of transport of electricity through space occupied by matter, gaseous, liquid, or solid, constitutes the larger problem of electrical conduction.

The restraint which a material offers to the passage of electricity from point to point of the substance differs at ordinary temperature with the nature of the material, so much so that substances are divided into two classes, insulators and conductors. If, however, the temperature be raised or lowered, it is found that the ratio of this restraint to the passage of electricity in insulators to the restraint to its passage in conductors changes greatly. When the temperature is exceedingly low, the restraint of insulators to the passage of electricity is practically infinite

and the restraint of metallic conductors upon the passage of electricity is practically *nil*. When, on the other hand, the temperature is exceedingly high, the insulators all cease to insulate and the restraint upon the passage of electricity through conductors is greatly enhanced. Thus the ratio, resistance of insulators to resistance of conductors, tends to approach unity with rise of temperature, and we may with probability assume that at 4000° K., the temperature of vaporized carbon, insulators which have become gaseous and conductors which have become vaporized all offer about the same restraint to the passage of electrons from point to point in a space filled with these materials.

The problem of the transport of electricity naturally assumes two aspects: Why does the same element or compound change in conductivity when the temperature changes, and why do different elements or compounds have a different conductivity at a given temperature? In discussing these aspects of the large problem of conduction it should be borne in mind that other conditions than temperature affect electrical conduction. It is modified to a certain extent by many agencies, as magnetism, light, crystallization, and by variations in pressure. But we shall ignore these agencies of minor influence, and assume that the pressure is always atmospheric. Great temperature changes combined with great pressure changes must, however, finally be applied to matter before the physics of matter as found in Nature can be fully considered.

So far as known, the elements especially, and many of the more stable compounds, when brought by temperature to the liquid or vapor phase, are unique in that all marks of physical and chemical past history are erased. Hence when the elements at least are in these phases their electrical conductivity may be studied freed from all those accidental influences (as crystallization, magnetism, mechanical treatment, etc.) which tend to obscure the essential features sought.

In order to bring many of the elements and inorganic compounds into their liquid and vapor phases, means must be provided for producing very elevated temperatures, which for quantitative work must be regulated and measured.

We shall now consider some of the questions involved in the study of metallic conduction at elevated temperatures and under normal pressure. It must be borne in mind, however, that we do

not consider that electrical conduction is fully investigated in a broad way and with any pretence to completeness until the manner of transport of electricity through matter is examined experimentally under all the possible conditions of pressure and temperature to which it may be submitted.

IV. DIVERSITY IN THE ELECTRICAL CONDUCTION OF MATTER.

In *Metallurgical and Chemical Engineering* for January, 1915, Dr. Carl Hering has gathered together in five curve sheets a "Comparison of Electrical Resistivities at High Temperatures" of a large number of elements and simple compounds. These curves give a summary of much of the experimental data on resistivities from 273° K. to the highest temperature at which data have been obtained. Curves of a few of the metals plotted from data obtained chiefly by the writer for metals which are molten at high temperature, and from data obtained by others for metals not molten at high temperature, are extended to 1773° K. and above. Curves for simple compounds are carried in several cases to 1373° K., and one curve for alundum (data obtained by the writer) to 1873° K. In "Measurements of Electrical Resistance," by W. A. Price, is given a chart, facing page 14, in which curves are shown for thirty metals and alloys below the temperature of 473° K. and extended down to 73° K. and still lower in a few cases. These data are the summary of the work of Matthiessen and Hockin, first published in 1860 and 1862. Data upon the resistivity of gold, platinum, mercury, and lead at temperatures within two or three degrees of the absolute zero have been obtained recently by Kamerlingh Onnes. Some of Onnes's curves for gold, platinum, and mercury have been reproduced by the writer on page 377 in volume xxv of the *Transactions of the American Electrochemical Society*.

In examining these various curves, even though the attention is confined to the curves of the pure metals, one is struck with the great diversity in resistivities at any given temperature. It appears that in no single case, also, does a metal fail to show inflections in its curve if it has been studied over a long range of temperature, and that whenever the metal changes state, in passing from solid to molten, its curve changes abruptly. It at once becomes apparent that it would be impossible to embody the facts of metallic conduction as revealed in these curves, and still

less the facts of the conduction of compounds, in general equations, provided these equations are to apply over any considerable range of temperature. Nevertheless, theories of metallic conduction have been proposed and equations have been deduced that rest upon a theory which seems to fit the facts for change in metallic resistance with temperature, provided the temperature range considered is sufficiently restricted. But no theory has yet been proposed, capable of taking mathematical form, that can account for the facts of metallic conduction over any extended temperature range, particularly if the range takes the metal through a change of state, or, indeed, through any change in its molecular aggregation. It may be true that a guiding and coördinating principle may be contrived of very hazy outline, but no *law* of resistance change or explanation of absolute resistivity under a given condition, which has any pretence to precision, has so far been announced. We shall, however, consider the most generally accepted theory of metallic conduction and then propose a hypothesis of our own. Before doing so, however, it will be convenient to consider first the principles of the methods which at present seem well adapted to the study of electrical conduction at temperatures exceeding 1273° K. and to offer some comments on the facts of conduction which have been ascertained so far.

V. THE PRODUCTION OF HIGH TEMPERATURE FOR THE EXPERIMENTAL STUDY OF ELECTRICAL CONDUCTION.

All bodies tend to come into both temperature and chemical equilibrium with their surroundings. If high temperature wipes out the past physical history of bodies, it tends, on the other hand, to establish new chemical equilibria. Materials in general, and pure metals in particular, generally suffer large alterations in resistivity from very slight chemical reactions or from the addition of small amounts of foreign materials. It is to be noted, also, that when materials are heated to a high temperature under low pressure they evaporate and finally boil, the more readily as the pressure is made lower. The above properties of matter require careful consideration in planning methods for the study of electrical conduction at high temperature.

For accurate quantitative work in the measurement of electrical resistivity at high temperature it is necessary to devise a

means of producing, by gradual gradations, not only a high temperature but a temperature which can be made uniform throughout a considerable volume. Furthermore, it is convenient and very desirable that the material to be studied should be under a pressure at least not below the normal, and, for the solution of certain problems, it should be possible to submit the material to be measured to pressures which greatly exceed the normal. If the pressure is greater than zero it becomes necessary to immerse the material under study in some other substance, gaseous or fluid, and at the same time meet the condition that the temperature equilibrium between the material under study and the substance in which it is immersed shall remain unaltered throughout the entire temperature range in which measurements are to be made. If the material being studied becomes fluid or gaseous at any temperature employed, then a container must be provided. The material of this container must likewise remain at all temperatures used in chemical equilibrium with the material studied. Furthermore, since every compound and certain elements are porous at high temperature (to the extent that the substance, if gaseous, in which they may be immersed is physically absorbed into their pores), precautions must be adopted that the true conductance of the material is being measured and not the conductance of the material plus the conductance of the gas, vapor, or fluid held mechanically in the interstices of the specimen. Thus, if the conductivity of Al_2O_3 powder is measured at 1550° C. when immersed in a $CO + N$ atmosphere, too large a value by some 20 per cent. would be obtained for its conductivity, because the conductivity of the Al_2O_3 and the gas in its interstices would be measured together in parallel.[1]

These are hard requirements for the study of electrical conductivity at high temperature, and the difficulties encountered in meeting them increase at a greatly accelerated rate as the temperature is made to exceed 1000° C.

The production of a uniform and controllable high temperature throughout a volume of considerable dimensions has been accomplished by the writer by the construction of an electric furnace which employs a heater of pure Acheson graphite. By

[1] Consult "Methods, Data and New Apparatus for Measuring Electrical Conductivity Above 1500° C. of Vapors at Normal Pressure," by Edwin F. Northrup, JOURNAL OF THE FRANKLIN INSTITUTE, March, 1915, p. 352.

heating in cascade the highest temperatures are readily produced. In applying this principle an outside graphite heater is encased in refractory materials and is heated to a temperature which these refractories will endure. Another inside and smaller graphite heater is suspended from above by massive graphite electrodes. When the outside heater has been raised to 1500° or 1600° C. the inside heater is further heated electrically to any temperature desired up to the temperature where graphite vaporizes under normal atmospheric pressure.[2] If means were to be provided, as they might be, for greatly increasing the pressure, it is probable that still higher temperatures could be produced. When avoiding the use of a vacuum or low pressures, for the reasons stated, it is necessary to determine what material, if any, gas, liquid, or solid, can be used in the furnace, which will remain in chemical equilibrium both with the furnace walls and with the specimen, the resistivity of which is to be measured. The determination of this matter alone involves much research. Certain it is, however, that the walls of the furnace will be in perfect chemical equilibrium with the gaseous products which remain in the furnace after a certain very small portion of the graphite has interacted with the original air or gas in the furnace (provided new quantities of gas or air are not admitted—a matter easily cared for). When no gas other than air enters the furnace, the product which remains after all interaction between air and graphite has ceased is, presumably, CO + N, though at very high temperatures finely-subdivided particles of pure carbon are also present. It is experimentally found that many, though by no means all, metals give every evidence of being chemically inert in this mixture of gases. Several metals, on the other hand, are chemically and physically modified at a high temperature when immersed in this gas mixture. Thus molybdenum and tungsten become brittle and the melting-point of platinum is much lowered. Copper, gold, and tin, on the other hand, give no evidence of any chemical interaction with CO + N even at a temperature as high as 1500° C. or higher. The writer has not worked with other gases, as nitrogen, hydrogen, etc., and is unacquainted with the phenomena which would be manifested. It would be an excellent line of investigation to determine the conditions of chemical equilibria and chemical

[2] A furnace and cascade attachment has been described by the writer in *Metallurgical and Chemical Engineering*, January, 1914, and May, 1914.

interaction of the metallic elements, also the solid non-metallic elements, with the gaseous elements and the gaseous compounds at high temperature. How, for example, would molybdenum behave at 1500° C. in a vapor of carbon tetrachloride?

Experience has shown that a furnace of small size cannot with best advantage be furnished with a heater unit of pure graphite because the consumption of a small amount of the graphite has a large percentage influence in the destruction of the heater unit, and, furthermore, graphite in small masses is not strong mechanically. For this reason the small model furnace, designed by the writer, employs a highly refractory metal as a heating element. The unit, of refractory material in which this metal is held, is encased on the outside and lined on the inside with graphite. The oxidation temperature of the graphite is lower than that of the metal, and before the metal has opportunity to oxidize a small portion of the graphite lining oxidizes, filling the furnace with a CO + N atmosphere which permanently protects the metal from oxidation.

The General Electric Company has developed an excellent molybdenum wound furnace in which the molybdenum winding is protected from oxidation by being maintained in an atmosphere of hydrogen. This type of furnace, however, is unsuited for the heat treatment of materials which absorb or are in any way affected by hydrogen, and it could not, therefore, for this and other reasons, be employed with advantage in determining the resistivity curves of several of the metals.

To obtain the uniform temperature required throughout a considerable volume, the writer has used the principle in both his large and small types of furnaces of causing the heating current to pass lengthwise many times from one end to the other of a cylindrical-heater unit instead of going circularly around it, or passing but once, at very low voltage, through a cylindrical tube. This disposition of the heating current gives almost perfect black-body conditions throughout a considerable portion of the furnace chamber.

The measurements of the high temperatures employed is not less important for quantitative work than their production and control. The platinum *vs.* platinum plus ten per cent. rhodium thermocouple generally opens circuits and fails to operate in a CO + N atmosphere at a temperature in the neighborhood of

1500° C. It is troublesome to use and cannot be considered reliable, without frequent recalibration, at these high temperatures. Optical or radiation pyrometers, furthermore, are not well suited to precision work in the determination of the resistivities of the metals, chiefly because of the difficulties and labor of sighting directly upon the portion of the molten metal which is being measured, and also because observations are often required below a temperature where these instruments are useful or accurate. It was found desirable, therefore, to devise a new type of pyrometer, operating upon a new principle, which might be submitted to exactly the same temperature as the metal being measured and which would operate with perfect reliability as high as 1600° or 1700° C. Such a pyrometer was easily devised after the electrical and other properties of molten tin and molten lead had been studied. These two metals, tin in particular, melt at a low temperature and only evaporate appreciably or boil at a very high temperature, and, what is very essential in precision work, they increase in resistance when molten in a perfectly regular way to a very high temperature. The linear increase in tin with increase in temperature has been investigated by the writer and found to hold to at least 1680° C., and it is probable that this linear increase continues to near the boiling-point of tin, which exceeds 2000° C. Pure lead also increases linearly from its melting-point to 1600° C. This property of tin is employed in a very simple manner in the construction of a direct reading and direct insertion pyrometer for use up to 1700° C. or higher. As the increase in the resistance of tin is linear, it is possible and easy to so choose the resistances of the Kelvin double bridge used in measuring the resistance of the pyrometer that the indications of the bridge upon a uniformly-spaced scale read directly in degrees centigrade. At these high temperatures, however, parasitic and irregular electromotive forces always develop within the pyrometer, but their disturbing influence may be avoided, however, by using alternating current for the measuring current. This in turn requires the employment of a galvanometer in connection with the Kelvin double bridge which responds to alternating current only and which is not in the least affected by any direct electromotive force in its circuit.

Both pyrometers and galvanometers of the above types, which meet perfectly the required conditions, have been constructed, and

are being much used in measurements made by the writer and Mr. R. G. Sherwood, working under the writer's guidance. The problem, therefore, of measuring the temperature to at least 1700° C. is now fully and very satisfactorily solved.

More detailed descriptions of this method of measuring and reading temperatures will be given in later publications.

When the temperatures produced (as by means of the cascade attachment) exceed 1700° C., no other means for their accurate determination through a series of ascending values are now available than the well-known optical or radiation methods. It should be noted, however, that in applying these methods large inaccuracies may occur, due to an unknown absorption of light or radiant heat by fumes or absorbent gases in the furnace chamber, or by windows placed between the high-temperature zone and the instrument. When a very high temperature is produced in a vacuum-type furnace, the radiation must pass, not only through a window, the transparency of which is likely to become decreased by deposits on its under side, but also through absorbing vapors, which are much more prone to form at low pressure than they are at atmospheric pressure. It is therefore apparent that, when the highest temperatures are obtained in the cascade attachment at atmospheric pressure and with an uncovered opening through which observations into a region at black-body temperature may be made, optical and radiation methods of measuring temperature are relatively easy and little likely to be in error.

VI. CHARACTERISTIC FACTS OF METALLIC CONDUCTION NOW KNOWN.

The chemical elements, when studied by themselves under certain imposed conditions, show their characteristic phenomena more unmistakably than when two or more of the elements, physically or chemically combined, are studied. In seeking features, therefore, which are characteristic of a group of phenomena, as the phenomena of electrical conduction exhibited under widely-varied conditions of temperature, investigations should begin with the pure chemical elements. It thus becomes far easier to ascertain and to mentally abstract, for purposes of classification, for seeking analogies, or for tracing curves, those phenomena which are essential and characteristic than when complexities are added by studying the elements in physical or chemical groups. For this reason an investigation of metallic conduction should begin

with a study of the purest metallic elements obtainable, and the changes in the phenomena of the conduction of these elements should be traced as the one condition of temperature only is gradually varied through the widest range experimentally realizable. This searching procedure has recently been followed with much success. From the work so far done the metallic elements may be grouped in respect to their property of electrical conduction as follows:

1. Elements which either melt at so high a temperature or enter so readily at high temperature into chemical combinations with any surrounding substance that their resistivity curves have not been traced over a temperature range in which they pass through a change of state. To this group belong such metals as iron, nickel, cobalt, tungsten, molybdenum, tantalum, platinum, iridium, rhodium, etc.

2. Elements which upon becoming molten about double in resistance as they pass from the completely solid to the completely liquid state and thereafter increase in resistance with rise in temperature in a strictly linear way to near their vaporization temperature or to the highest temperature at which they have been examined. To this group belong aluminum, copper, tin, gold, silver, and lead.

3. Elements which upon liquefying suddenly increase in resistance and thereafter possess a positive temperature coefficient which is only approximately constant. To this group belong mercury, sodium, and potassium.

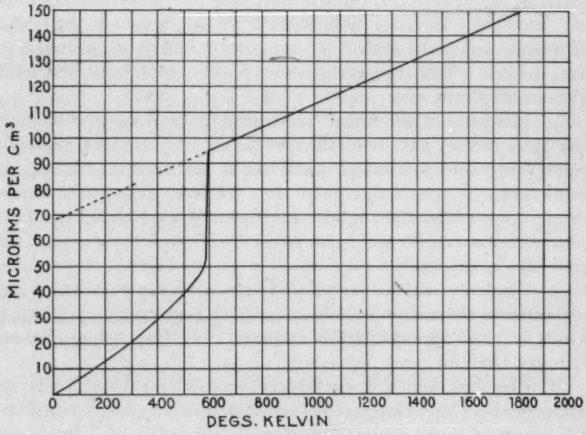
4. Elements which upon liquefying suddenly increase in resistance, about doubling, and thereafter possess over a considerable range of temperature a negative coefficient which gradually changes to positive before vaporization is reached. Zinc and cadmium are the only known representatives of this group.

5. Elements which upon liquefying more or less suddenly decrease in resistance and thereafter steadily increase. Antimony and bismuth are the only two known representatives in this group. Antimony was found by the writer and V. A. Suydam to exhibit an increasing rate of increase in resistance in the molten state, but the writer now believes this result needs reëxamination, as errors may have crept into the measurements made at the highest temperatures. Such errors could have occurred from the formation, by the container then used, of a gas which could change in an

unknown way the cross-section of the column of metal then being measured. The characteristics of bismuth, on the other hand, are known with certainty. This metal decreases in resistance with great abruptness upon becoming molten, the resistance becoming less than half. It thereafter has a strictly linear increase in resistance, certainly to 775° C. and probably to near its vaporization temperature.

The metals belonging to group 2 may be considered as having the normal characteristics of the electrical conduction of pure

FIG. 1.



Lead, typical resistivity curve.

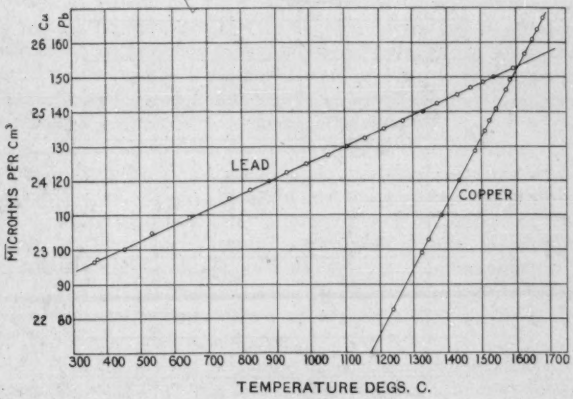
metallic elements. From the work done upon these metals at both low and high temperature we are able to give with considerable precision the resistivity curve of a typical metal, as lead, traced from very near the absolute zero to about 1873° K. The curve for lead is shown in Fig. 1.

It is to be noted that the resistivity of lead increases steadily from zero at 0° K., with a slight convexity in the curve toward the temperature axis, until the metal melts at 600° K., at which temperature the resistivity almost exactly doubles with abruptness. After fusion is complete the resistivity continues to increase

exactly proportional to the temperature until the metal boils. This increase in resistivity (and this is an important feature to note) is not sufficiently fast, however, so that a projection of the curve for the molten metal toward lower temperature cuts the temperature axis near the absolute zero. On the contrary, it cuts the temperature axis at about 1480° below the absolute zero.

In Fig. 2 we give, from data obtained by the writer and his assistants, curves for Bi, Pb, Sn, Au, Cu, and Ag, all plotted to the same scale, of the resistivities of these metals *vs.* the absolute temperature in their molten state. In Fig. 3 a portion of the

FIG. 3.



curves for lead and copper are repeated with the experimentally-obtained points shown upon the curves to give an indication of the precision of the observations.

These six metals increase in resistivity when in the molten state in a strictly linear manner. The extensions to the curves, shown in dotted lines, give the resistivities at the absolute zero which these metals would have if they continued molten to this temperature and continued to change in resistivity in the same way down to absolute zero. The vertical lines drawn at the temperatures (in degrees K.) at which the metals melt indicate by their free extremities the resistivities acquired by the metals when they pass from the liquid into the solid state.

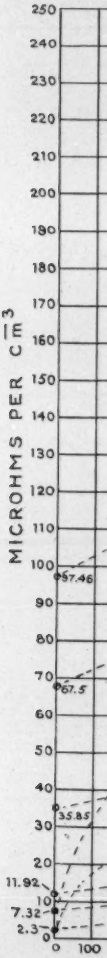
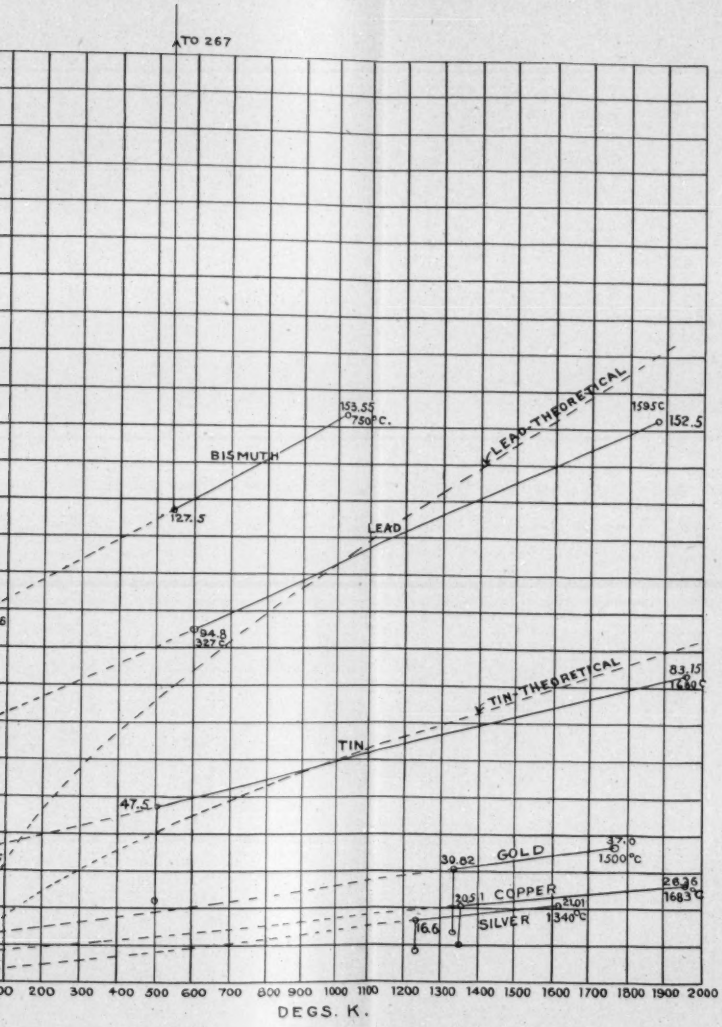
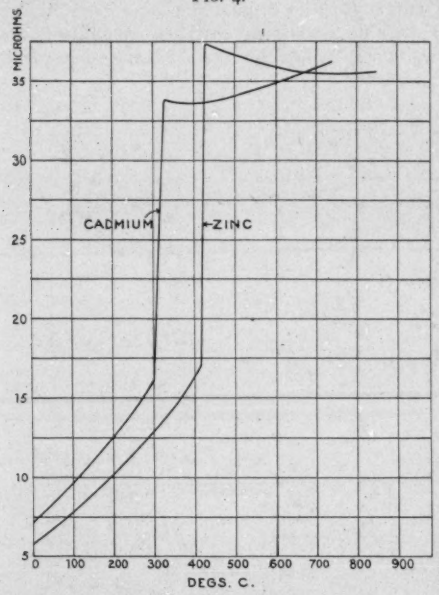

MICROHMS PER C.C.
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
97.46
67.5
35.85
11.92
7.32
2.3
0
100

FIG. 2.


TO 267
153.55
750°C.
BISMUTH
127.5
LEAD-THEORETICAL
LEAD
159.5C
152.5
94.8
327°C
TIN-THEORETICAL
83.15
TIN
47.5
30.82
GOLD
37.0
1500°C
20.51
COPPER
21.01
26.36
1683°C
16.6
SILVER
1340°C
200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
DEGS. K.

In Fig. 4 are given curves for zinc and cadmium in a temperature range where these metals, the only two representatives among the pure metals of group 4, are both solid and molten. The strongly-marked negative coefficient of zinc in the molten state is quite remarkable and forms a stumbling-block in any theory of metallic conduction thus far proposed. As the resistance of

FIG. 4.



brass also decreases with increase in temperature so soon as the brass becomes molten, the negative temperature coefficient of zinc appears to manifest itself even when alloyed with copper, which has a constant positive coefficient when in the molten state. As another example of the persistence of a property of an element when alloyed with another element may be mentioned the case of an alloy of tin and bismuth in atomic proportions. Both these metals have a positive and constant coefficient in the molten state,

and so has their alloy. The bismuth, however, which decreases in resistance, in passing from solid to molten, impresses this characteristic on its alloy with tin, though the decrease in the alloy is less in magnitude than in the bismuth itself. The curve for this alloy has been accurately obtained experimentally, by the writer and R. G. Sherwood, to a temperature of about 1100° C.

Some prominent facts of metallic conduction over a wide range of temperature are listed below:

a. All metallic elements exhibit at ordinary temperature a conductivity which is about a million times as great as the conductivity of electrolytes.

b. The general tendency of pure metals, but not of alloys, is to reach zero resistance at zero degrees Kelvin and to steadily increase in resistance with rise in temperature, except when the metal passes through a change of state or when from any cause the molecular aggregation changes (as when nickel or iron loses its magnetism from increase in temperature).

c. When a change of state occurs this change is, without exception, accompanied by a change in resistance, which is more or less sudden. If the change in state occurs very abruptly the change in resistance is also abrupt, as shown in the case of bismuth. If the change of state is somewhat gradual the change in resistance is less abrupt, as is shown when aluminum melts.

d. The general tendency is for the resistance to become linear when the metal becomes molten. So far as studied, this seems to be the tendency also with alloys.

e. The increase in resistance when the metal is molten is never so rapid that the curve when projected toward lower temperature ever cuts the temperature axis near zero degrees K., but always far below it.

f. An increase in metallic resistance is always accompanied by a decrease in density, and when, as happens in the case of antimony and bismuth, the density increases the resistance decreases.

g. The ratio, coefficient of resistance of molten metals which change linearly in the molten state to the coefficient of volume expansion in the molten state, is quite approximately the same for those metals which have been examined in this particular. The writer has directed attention to this feature in "Electrical Conduction at High Temperature and its Measurement," page 388,

Transactions of the American Electrochemical Society, vol. xxv, 1914. This ratio varies from about 3.48 to 5.34 as there given. More accurate measurements made recently have shown that the differences in these ratios are less than this.

h. When metals crystallize, when they are powdered and probably when the powders of different metals are mixed together, and when metals are alloyed together, the resistivity is always increased. While there seem to be several exceptions, in a very general way metals of high atomic weight have high resistivity.

When the pure metals had been examined in the solid state only, and it was found that their projected resistivity curves all pointed toward the zero of absolute temperature, the attempt was made to explain these facts of metallic conduction by an application of the new electron theory. A formula, based upon a theory of free electrons within the metal, was proposed. The formula expresses the assumed infinite conductivity of the pure metals at zero degrees K. and its continual decrease without curve inflections with increase in temperature. As this free electron theory of metallic conduction has enjoyed the support of eminent authority and is given in recent literature as the most probable theory, we have a circumstance which justifies us in presenting here its essential aspects and inquiring if it is sufficient to cover the facts, or if a better hypothesis may be offered. We proceed to this presentation and endeavor.

VII. METALLIC CONDUCTION: THEORY OF CONDUCTION BY FREE ELECTRONS.

The hypothesis adopted to account for metallic conduction is derived from the kinetic theory of gases. The assumption that the mechanism of metallic conduction consists of free electrons was introduced into electronic theory by Drude and J. J. Thomson.

We may picture the views of these authors as follows: Conceive the molecules of a solid metal as not completely filling the space of the volume which contains them. The unoccupied space existing among the molecules would result from the geometrical reason that closely-packed bodies which approach a spherical form occupy only a portion of the volume in which they are contained, or the unoccupied space might result from the fact that the average separation between centres of adjacent molecules is

greater than the average diameter of the molecules. The molecules themselves are conceived as capable of being carriers of electrons, and that any molecule is electrically neutral when the sum of the negative charges of the electrons associated with it is equal to the positive charge held by the molecule. The theory assumes, however, that not all the electrons required to make the molecules neutral remain attached to the molecules and thus partake in the motions of the molecules which result from heat agitation. On the contrary, it is assumed that a certain portion of all the electrons in the unit of volume become detached from the molecules, and that they move about as individual units, pursuing zigzag paths among the molecules in the unoccupied space. Those electrons which remain attached to the molecules are called bound electrons, and those which become detached from the molecules of the metal are called free electrons. It is assumed, in short, that the movements of the free electrons are in all respects like the movements assigned to the molecules of a gas in the kinetic theory of gases. They are supposed to move with all possible velocities, but, on account of their great number, to possess for any given temperature a certain definite average velocity which can be calculated from considerations based upon the laws of probability. These free electrons are assumed to be the sole carriers of electricity when current flows in a metal.

By a well-known theorem in the kinetic theory of gases, the mean kinetic energy of a large number of particles of any kind or mass is the same for a given absolute temperature. This holds, whatever the nature or whatever the size of the individual particles. Thus in a mixture of two kinds of molecules the average kinetic energy of each kind is the same. Hence, as the mass of an electron is very small as compared with a molecule of gas, the average velocity of the free electrons, to possess the same average kinetic energy as an equal number of gas molecules at the same temperature, is far greater than the average velocity of the molecules. The electrons, however, are only carried, on the average, comparatively short distances before they encounter other electrons or molecules of the metal. Upon the basis of the above-assumed mechanism, J. J. Thomson arrives at an expression for the electrical conductivity of a metal as follows:

The expression for Ohm's law is that the current is equal to the electromotive force times the conductivity of the medium (con-

ductance through a unit length of a unit cross-section of the material) or,

$$i = kE \quad \ldots\ldots (1)$$

where k is the conductivity and E is the electric force per unit length of the conductor.

Assume that in the unit of volume of the metal there are n free electrons. Before an electromotive force is applied to the metal these n electrons will be moving, upon the average, as many in one direction as in another. Now let an electromotive force E per unit length of the conductor be applied. Call e the charge on an electron (all electrons have the same charge). Each electron will now be subjected to a force which will tend to give it a component of motion in a direction opposite to the direction of the force (opposite to and not with the force, because the charge on the electron is negative). Ee is the magnitude of the force on one electron. If the electron is free it will be accelerated in the opposite direction to the force and the acceleration will be

$$m\frac{d^2s}{dt^2} = Ee \quad \ldots\ldots (2)$$

where m is the mass of the electron, s is the distance which the electron moves, and t is the time. The velocity acquired by the electron at the end of a time t is

$$v = \frac{ds}{dt} = \frac{Eet}{m} \quad \ldots\ldots (3)$$

No constant from the integration appears in the right member of equation (3) because it is assumed that the electron starts from rest and begins to move when the time is zero, as it is supposed to lose at each encounter any velocity given to it by the electric force. Let T be the average time that elapses between two encounters of a free electron. Then the average velocity acquired by the electron between two encounters is

$$V = \tfrac{1}{2}\frac{EeT}{m} \quad \ldots\ldots (4)$$

The quantity of electricity transported in the unit of time is the electric current, and this will equal the number of electrons which cross unit of section of the conductor times the charge e on each electron. The number of electrons to cross a unit section of the conductor in unit time will be equal to n, the number per unit

volume which are free times the average velocity with which they move. Hence,

$$i = neV = \frac{Tne^2}{2m} E \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Since E is the electromotive force, $\frac{Tne^2}{2m}$ is the conductivity.

If L is the average distance which an electron traverses between two encounters (the so-called mean free path of an electron), $T = \frac{L}{V}$, and we derive for the conductivity

$$\sigma = \frac{Lne^2}{2Vm} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

According to the dynamical theory of gases, the kinetic energy of a particle or molecule is proportional to its absolute temperature, or,

$$\tfrac{1}{2} mV^2 = K\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where θ is the absolute temperature of the gas, m the mass of a molecule, V the mean velocity of a molecule, and K a universal constant; that is, a constant which is independent of the nature of the material considered. From equation (7) $V = \sqrt{\frac{2K\theta}{m}}$, and equation (6) becomes

$$\sigma = \frac{Lne^2}{2\sqrt{2Km\theta}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

also

$$\sigma = \frac{LnVe^2}{4K\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

or

$$\frac{1}{\sigma} = \rho = \frac{4K\theta}{LnVe^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

where ρ is the resistivity.

Equations (8) and (9) are the expressions for the conductivity of a pure metal ordinarly derived by making the hypothesis that a certain number n per unit volume of the electrons are free and have motions like gas molecules.

Of the quantities which occur in these equations we are completely ignorant, from any experimental evidence, of the mean free path L and the number of free electrons n. The mass m of an electron, the charge e on an electron, and the universal con-

stant K are known from experimental data, and V may be calculated. Thus,

$m = 8.8 \times 10^{-28}$ gm. when the velocity is slow.
$e = 4.7 \times 10^{-10}$ electrostatic units.
$K = 1.8 \times 10^{-16}$
$V = 1.16 \times 10^{7}$ cm/sec. at zero degrees C.

Referring to the expression for the conductivity given in equation (8), it is to be noted that the conductivity varies inversely as the square root of the absolute temperature. Experiment shows, however, that pure metals, when in the solid state, decrease in conductivity more nearly directly as the absolute temperature increases. Hence, to bring the theory into agreement with the facts, use is made of expression (9) for the conductivity, and the further assumption is made that the product LnV is constant. Since a metal has only a small expansion with increase in temperature, we should expect that L, the mean free path, would remain nearly constant, and, as the average velocity of the electrons must certainly increase when the temperature increases, there is a necessity for the assumption that n, the number of free electrons, *decreases* when the temperature *increases*. This quite arbitrary and unlikely assumption, unsupported by any experimental evidence, would alone appear sufficient to lead to a rejection of the theory. It probably would have done so if it were not for the further support which the theory appears to acquire when it is applied to a calculation of the ratio of the thermal to the electrical conductivity, and to the explanation which it seems to give of thermo-electromotive force.

By a process of reasoning based upon the theory, but which we cannot take space to give here, an expression is reached for the ratio of the thermal to the electrical conductivity, which appears to accord, in a limited range of temperature, fairly well with the facts. The expression is:

$$\frac{k}{\sigma} = \frac{4}{3}\left(\frac{K}{e}\right)^2 \theta \qquad (11)$$

For 18° C. this expression gives:

$$\frac{k}{\sigma} = 7.15 \times 10^{-11} \qquad (12)$$

This result means that the ratio of the thermal to the electrical conductivity is proportional to the absolute temperature, and for any given temperature is a universal constant; that is, the same constant for any kind of material. The conclusion expressed in equation (11) is known under the name of the "Wiedemann-Franz Law," and for a temperature range between 0° C. and 100° C. agrees remarkably well with the experimental facts in the case of the pure metals.[3] Whether or no this law continues to hold when the metal passes through a change of state, is not known, so far as the writer is informed. A rough experiment, made by the writer on the thermal conductivity of tin just before and just after fusion, gave somewhat ambiguous results, but seemed to indicate that the law does not hold. This experiment should be repeated with care in the case of several metals having low fusion points.

The writer would like to give a further explanation and defence of the free electron theory of metallic conduction, but lack of space compels him to proceed at once to his reasons for rejecting it, and to the presentation of a hypothesis which appears to him to give a more natural and better account of the experimental facts.

The writer rejects the free electron theory of metallic conduction for the following reasons:

1. It is highly artificial. Since a mass of any metal is very nearly electrically neutral, if the space in the interstices of its atomic groups is occupied with a large number of negative electrons, then these atomic groups must be electrically strongly positive. A condition must therefore exist which is unlike anything ever observed, for we must suppose that many electrons continue to remain free in space while being acted upon by the attractive forces of positively-electrified atomic groups. If it be supposed that the electrons are being continually knocked off by the violent collisions resulting from the heat agitation of the atoms and molecules, then there should be many more free electrons at high than at low temperature. But the facts are, that when the temperature approaches absolute zero the con-

[3] See Table V, p. 68, "Modern Electrical Theory," by Norman Robert Campbell.

ductivity of a pure metal approaches infinity, and this can only be accounted for, upon the theory, by assuming an increase in the production of free electrons at very low temperature. What are the forces at 2° K., where the atomic groups are almost completely quiescent, which would maintain negative electrons free in space among the interstices of highly-charged positive atomic groups?

2. The theory of free electrons offers no explanation of the sudden change in resistance which occurs with a change of state of the metal. The sudden rise or sudden decrease in resistivity which occurs when a metal melts could be explained only on the theory of free electrons by supposing that when a metal very slightly expands upon liquefying, there is an enormous and sudden decrease in the number of free electrons in the metal, and if the metal very slightly contracts upon liquefying, there is an equally and sudden increase in the number of free electrons. Such assumptions, for which there is not the slightest evidence, would only be made to force the theory to agree with the facts. No formulæ which rest upon a theory of free electrons can be written which even approximately express the relation between resistivity and temperature over a range of temperature which includes changes of state in the metal, unless additional hypotheses are introduced which are more artificial than the original hypothesis.

3. The theory of free electrons can only pretend to account for a *change* in resistance of a given metal with temperature. It has no explanation to give for the different resistivities of *different* metals when at the *same* temperature.

4. What becomes of the free electrons when a metal is vaporized and the vapor is expanded? Do they reënter the atoms when these become far separated by expansion but leave them again when the vapor condenses, and then continue to increase in number in the interstices of the atomic groups, becoming most numerous when the metal is solid and its atomic groups have become quiescent at a near approach to absolute zero? There is no direct evidence that free electrons exist anywhere, except it be in a very high vacuum, and even here (as in the stream of free electrons observed in the Coolidge X-ray tube) it is hard to conceive of the existence of a volume distribution of electricity of one sign only.

VIII. METALLIC CONDUCTION: ELECTRIC TRANSPORT HYPOTHESIS.

In seeking a hypothesis respecting the nature of the process of metallic conduction, it appears to the writer profitable to avoid introducing any assumptions of the existence of a mechanism, or of a condition which cannot be directly observed. It seems desirable rather, to attempt an explanation of the process of electrical conduction, where the process cannot be directly observed, by assuming it to be similar in character to a species of electrical conduction which may be directly observed. Thus suppose two insulated metal bodies are located a short distance apart, and that they are joined, one to the positive and one to the negative coating, of a charged Leyden jar. If now a small insulated conducting body continually makes excursions between the two metal bodies, it will at each double excursion transport a certain quantity of negative electricity from the negatively-charged coating to the positively-charged coating, until the Leyden jar is wholly discharged. In this process of electric transport we have a species of electrical conduction which may be directly observed and its laws fully determined. The existence also, and the magnitude of the ultimate unit of negative electricity, may be directly observed and measured. If, therefore, we can show how the process of the passage of electricity through a metal is a process of the same general character as the observable processes of electric transport and that it is the negative electrons which are transported, we have explained metallic conduction without introducing artificial mechanisms or conditions, so far as any explanation is possible.

Now any hypothesis, theory, or explanation of metallic conduction to be adequate must give a reasonable account of the experimental facts—not over one or two per cent. of the temperature range in which experimental facts have been obtained, but over the entire temperature range in which such facts are known. This range certainly extends, at the present time, from about 2° K. to about 2000° K.—a range in which many metals pass from solid to liquid and finally vaporize. An adequate hypothesis then must at least coördinate and give a reasonable, if not a numerical, account of the fundamental facts of conduction as stated in Section VI above.

If we select a metal which exhibits a normal behavior, as lead, the curve of which is given on page 638, Fig. 1, we may express

its change in resistivity with temperature by means of an empirical expression of the following form:

$$\rho_\theta = \left|\begin{matrix}\theta_s \\ o\end{matrix}\right. \rho_o(1 + \alpha\theta + \beta\theta^2) \left|\begin{matrix}\theta_b \\ \theta_e\end{matrix}\right. K + \delta\,(\theta_b - \theta_e) \quad \ldots\ldots\ldots\ldots (13)$$

Here $\left|\begin{matrix}\theta_s \\ o\end{matrix}\right.$ means that only the symbols which precede the second vertical line apply when the temperature lies in the limits o and θ_s degrees Kelvin, where θ_s is the highest temperature at which the metal is solid, and the symbol $\left|\begin{matrix}\theta_b \\ \theta_e\end{matrix}\right.$ means that only the symbols which follow the second vertical line apply where θ_e is the temperature in degrees Kelvin at which the metal has become wholly liquid, and θ_b the temperature at which it boils. α and β are coefficients which must be experimentally obtained for the metal in the solid state. K is the resistivity of the metal just after fusion at temperature θ_e, and δ is a constant which determines the rate at which the resistivity increases when the metal is in the liquid state.

In seeking a theoretical basis for the above purely empirical equation, we shall make use of certain fundamental, but not artificial, assumptions, but before doing so it will be well to consider certain relations between current and energy which are independent of our assumptions, and of the particular form of any theory of metallic conduction.

Current and Energy Relations.

In deducing these relations we accept as proved by experiment that there exists an indivisible and ultimate quantity of electricity called the electron, and that it is equal approximately to 1.57×10^{-20} electromagnetic units. With the above understood, consider the work done when by any process whatever electrons pass from a point P_1 to a point P_2. If a unit charge of negative electricity moves by any path whatever from the point P_1 at potential V to point P_2 at potential o the work done by the electric forces will be

$$W_1 = 1 \times (V - o) \quad \ldots\ldots\ldots\ldots (14)$$

If E units move in this manner, the work done will be

$$W_2 = EV \quad \ldots\ldots\ldots\ldots (15)$$

Let us analyze the character or nature of this work. Suppose the negative electricity which moves from P_1 to P_2 is distributed over the surface of a very small sphere, and that in its passage from one point to another the sphere moves in a perfect vacuum; then the work done will take the form of some type of electromagnetic radiation which probably will manifest greatest intensity when the velocity of the charged sphere is reduced quickly to zero upon arriving at the point P_2. If, on the other hand, the charged sphere makes its journey from P_1 to P_2 against a frictional restraint, or if it passes through the midst of a multitude of perfectly insulating molecules of matter with which it makes frequent encounters, it will, in the first case, develop heat by friction, and, in the second case, by augmenting the agitation of the molecules with which it collides.

In other words, we assume that a movement of electricity from a point P_1 to a point P_2 will manifest the energy involved in its passage along a potential gradient in the form of heat, *provided the charge does not move in a vacuum*, and it may be assumed that the same quantity of heat is developed, whatever be the mechanism of the transfer from P_1 to P_2, provided no work is done in producing a permanent chemical separation of atoms nor in generating electromagnetic radiation. Hence it follows that however we regard the details of the mechanism of metallic conduction we may expect the current to show the same heating effects.

By the simplest deductions the following ordinary relations are obtained: Calling I the current and t the time,

$$P = \frac{W_2}{t} = IV = \text{the power} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

The work done in the unit of time is

$$W_2 = IV = JH, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

where J is Joule's equivalent and H the quantity of heat. By Ohm's law the potential is

$$V = IR.$$

Hence

$$H = \frac{PR}{J} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

If R is taken in ohms, I in ampères, then H, in gramme calories per second, becomes

$$H = 0.24\, RI^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

Process of Electronic Transfer.

As we have shown that whatever be the process or whatever be the path by which electrons move from P_1 to P_2 the work done by the electric forces is the same, it is unnecessary to consider in detail the process whereby the conductor is heated by the passage of the current.

The process of electronic transfer may be considered from a physical point of view as follows:

It is assumed that when the temperature is not extremely high (1000° C. or higher) all the electrons in the metal are held attached by attractive forces to atoms or to atomic groups, and participate with the atoms or the atomic groups in their heat motions. It is also assumed that if any cause detaches an electron from an atom, the atom becomes a positively-charged body and exhibits all of the electrical properties of a small positively-charged particle.

It is further assumed that under electric stresses of ordinary intensity an electron will only leave one atom and pass to a near-by atom when, by the heat motions of the atoms or by an increase in the closeness of packing of the atoms (which results from an extreme lowering of temperature, great pressure, or both), two atoms or groups of atoms come within a certain very small distance of each other, which we shall call the contacting distance. In other words, metallic atoms, and several atoms when united into groups to form molecules, behave as perfect conductors, and the spaces between groups of atoms behave as perfect insulators. In considering an atom as a perfect conductor it is unnecessary to conceive that an electron can pass through an atom on the line of a diameter, but only that it can pass without restraint from a side of an atom facing the left to a side facing the right, perhaps by sliding without resistance over the surface of the atom.

This last assumption is not intended to preclude the possibility of an electron becoming detached from an atom by the violent collision of two atoms. This may occur, and before the electron can attach itself again to the same or another atom it may be swept out of the metal along the line of a very steep potential

gradient. As an example of this occurrence, when a metallic filament (tungsten wire) is raised to a high temperature in a vacuum the atoms collide violently with one another, and electrons become momentarily torn off from some of the atoms. If there is now an electric stress, which acts radially to the filament, and the gradient of this stress exceeds the stress between a detached electron and the nearest positively-charged atom the electron is swept out of the attraction of the nearest positive atom along the line of the electric stress and becomes one of the carriers in the well-known thermionic current. We assume this to be the process in the production of the thermionic current in the Coolidge X-ray tube.

If a heated wire is in an atmosphere instead of in a vacuum, the atmosphere surrounding the wire is ionized both by the violent collisions of its molecules and by the bombardments of electrons forced out of the wire by an electric stress. If the electric stress is removed, our theory assumes that an electron which might become momentarily free will attach itself to the first positively-charged atom, molecule, or group of atoms with which it comes into close proximity, and when attached will move with the atom or molecule as this moves unless again knocked off by a violent collision.

We may now attempt to derive a formula based upon the above physical ideas and assumptions for the conductivity or resistivity of a pure metal. As shown above, no single formula can express the physical facts of the conductivity of a pure metal from the absolute zero of temperature to the boiling-point of the metal, and the first formula which we shall derive may only be expected to apply, even approximately, over the temperature range in which the metal is molten and only for those metals which are normal in their behavior, having a resistivity curve of the same type, as lead.

Assume a_1, a_2, a_3, a_4 to be a single row of groups of atoms, which we shall call molecules.

Assume that these molecules are oscillating in the line $O - X$, and move from position 1, designated in Fig. 5 by $\oplus$, to position 2, designated by $\circ$.

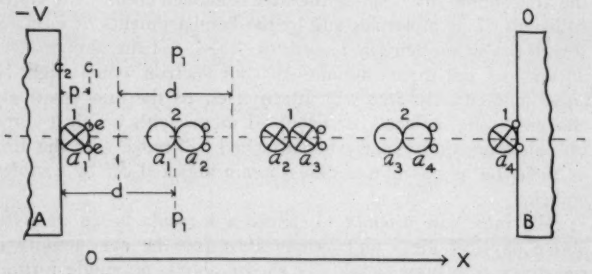
Assume that, attached to and carried on the surface of each molecule are a number of electrons (two in the figure), and that,

when there is no electric stress, each molecule is electrically neutral.

First consider the function in transporting electrons, of the four molecules represented in Fig. 5 as oscillating accurately in the same line parallel to $O-X$. Let there be an electric stress of intensity F in the direction $X-O$. At zero time assume the molecules to be in position 1. Then at this time a_1 receives k electrons from plate A.

It appears reasonable to suppose that the number of electrons which a_1 receives from plate A will be proportional to the intensity F of the electric field in the direction $X-O$; for we may consider that electrons will continue to collect upon the side of

FIG. 5.



a_1 facing plate B until they are in sufficient number to produce an electric field equal in intensity and opposite in direction to the external electric field. There will then be zero potential difference (from c_2 to c_1) between the sides of a_1 facing A and facing B, and then there will be no further force acting to move electrons. As the potential difference, due to the external field from one side to the other of a molecule in the line $X-O$, will be proportional to the diameter of the molecule, we can say further that the number of electrons k to pass from plate A to the right side of molecule a_1 will be proportional to the diameter of the molecule. Call the diameter of each of the molecules ρ. We should then have $k \propto \rho F$. At time t_1 let a_1 collide with a_2. We may assume that at the moment of this collision a_2 receives from a_1 the extra electrons which it acquired from plate A. It receives these elec-

trons, which at once pass to the side of a_2 facing B, on account of the fall of potential over the diameter of a_2 due to the external electric field. At the same time a_3 will also be colliding with a_4, which likewise received k electrons from a_3.

At time t_2, a_4 will have returned to plate B and a_1 to plate A, and the k electrons on a_4 will have been delivered to plate B.

Thus in each interval of time δt the molecules will all have made a double excursion and k electrons will have moved in an opposite direction to the electric stress a distance $2d$ equal to twice the average distance between centres of molecules lying in the line of the electric stress.

The quantity of electricity which moves in this interval will be proportional to the number of electrons, $k \propto \rho F$, and to the charge e carried by an electron. Calling δq the quantity of electricity transported by a single row of molecules in the interval δt, we then have

$$\delta q \propto \rho e F \ldots\ldots\ldots\

of molecules, σ, the conductivity, or conductance through unit cross-section per unit length. We shall then have, as an expression for the conductivity of the material,

$$\sigma \propto w\mu\rho e \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

We are ignorant of all the quantities on the right side of equation (24) except e, the electronic charge. It would be impossible, therefore, to obtain an accurate numerical confirmation of this relation. It is possible, however, by making certain additional assumptions which appear reasonable, and which, at least, are not artificial, to deduce from the relation 24 another expression for the conductivity of a pure metal which may be compared in several particulars with facts experimentally ascertained.

Let us suppose the metal to be in the liquid state. Call N the number of molecules, or atomic groups, in a unit cube of the material when at temperature θ. Let us consider only the component of velocities which these molecules have in the direction of the electric stress, as this is the only component which transmits electrons. Let the average velocity of the molecules in the line of the electric stress be called v. Now w, the number of encounters which take place over the unit of area at a given instant, will be proportional to the probable number of collisions of molecules moving to the right with molecules moving to the left.

If we call r the radius of a molecule, an encounter will occur whenever two oppositely moving molecules lie on the same plane a distance $2r = \rho$ apart. Then when an encounter between two oppositely moving molecules just occurs by tangential contact, the area occupied upon the plane of contact by these two molecules is $a = 2\pi r^2$, and the total area on the plane of contact occupied by molecules so located as to make a contact possible is

$$A_l \propto Na \propto N\pi r^2.$$

As the total area of the plane is taken as unity and A_l is the portion of the total area favorable to a contact, we obtain for the probability of a contact,

$$P \propto \frac{A_l}{1} \propto N\pi r^2 \propto N\rho^2 \ldots\ldots\ldots\ldots\ldots\ldots (25)$$

where ρ is the diameter of a molecule. But this probable number of contacts is proportional to the quantity w in equation (24), which may now be written,

$$\sigma \propto N\rho^3\mu e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (26)$$

Calling m the mass of a molecule and v its average velocity, its kinetic energy will be $\frac{1}{2}mv^2$, and this energy will be proportional to the absolute temperature θ of the metal. From this we derive $v \propto \frac{\theta^{\frac{1}{2}}}{\sqrt{m}}$. Now the average distance through which any molecule can oscillate will be equal to $d-\rho$ (Fig. 5) where d is the average distance between centres of molecules having the diameter ρ.

We may then write,

$$\mu = \frac{v}{d-\rho} \propto \frac{\theta^{\frac{1}{2}}}{(d-\rho)\sqrt{m}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (27)$$

and by substituting this value of μ in equation (26) our expression for the conductivity becomes

$$\sigma \propto \frac{N\rho^3 e\,\theta^{\frac{1}{2}}}{(d-\rho)\sqrt{m}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (28)$$

or the expression for the resistivity becomes

$$\rho_1 \propto \frac{(d-\rho)\sqrt{m}}{N\rho^3 e\,\theta^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (29)$$

Equation (28) tells us that the conductivity of a metal for *constant volume* and *constant number of molecules* should increase as the square root of the absolute temperature. The interpretation to be put upon this is that the *resistivity* of a metal should grow less with increase in temperature, *provided the pressure is maintained so that the volume of the mass does not change*. This decrease in resistance with temperature is found, in fact, to be the case with liquid mercury, according to the statements of Charles A. Kraus. He shows[4] " that when liquid mercury at 20° C. is heated at constant volume its resistance *decreases* by 0.069 per cent. per degree, whereas when heated at constant pressure its resistance *increases* 0.089 per cent. per degree," and

[4] *Physical Review*, vol. iv, September, 1914, p. 161.

he concludes that "*the increase in resistance of liquid mercury with increasing temperature is due to its decrease in density.*"

It is also a rather significant fact that pure graphite, which has an extremely small expansion, decreases slightly in resistance with increase in temperature.

As ordinarily made, the measurement of the resistance of a liquid metal is taken between potential points located on a column of the metal, and the pressure is atmospheric and constant. As the temperature rises the metal expands, and this expansion certainly increases the average distance d between centres of the molecules. How much the proportionate increase between centres of molecules is we do not know certainly, and it is useless to make assumptions so chosen that for any particular metal the expression for the resistivity would agree with the experimentally-gotten curve for the metal. We can profitably assume, however, that d increases as the density of the metal decreases.

The factor $\sqrt{m}$ shows that on this theory the resistivity should be large for metals of large molecular weight, though the occurrence of the factors N and ρ^3 in the denominator of equation (29) makes this conclusion uncertain. However, in a very general way such seems very roughly to be the case. Thus lead, with an atomic weight of 207.1, has a resistivity at 20° C. of about 21 microhms, and tin, with an atomic weight of 119, has a resistivity of 11.4. The atomic weight of potassium is 39.1 and its resistivity is 7.11, and the atomic weight of sodium is 23 and its resistivity is 4.87. The atomic weight of gold is 197.2 and its resistivity is 2.44, and the atomic weight of copper is 63.57 and its resistivity is 1.72. These figures do not mean much, however, as the molecular weights in the solid state are unknown.

Since the cubical expansion of some metals has been determined through considerable ranges of temperature, it seems permissible to make the assumption that $d = d_0 + 3a\theta$ where d_0 is the distance between centres of molecules at 0° K., and a is the coefficient of linear expansion. But when the molecules are absolutely at rest, as they are supposed to be at the absolute zero, we would have $d_0 = \rho$, the diameter of a molecule, and we obtain

$$d = \rho + 3a\theta \qquad (30)$$

Substituting this value of d in equation (29), we obtain

$$\rho_1 \propto \frac{a\sqrt{m}\,\theta^{\frac{1}{2}}}{N\rho^3 e} \qquad (31$$

Further, let N_0 be the number of molecules in the unit of volume at 0° K. Then if N is the number of molecules in the unit of volume at the temperature θ, we have $N = \frac{N_0}{V_\theta}$, where V_θ is the volume to which the unit of volume expands at $\theta°$. If we assume that the expansion is proportional to the temperature, then $V_\theta = 1 + b\,\theta$ and $N = \frac{N_0}{1 + b\theta}$, which value substituted in equation (31) gives

$$\rho_1 \propto \frac{a\sqrt{m}\,\theta^{\frac{1}{2}}(1 + b\theta)}{N_0 e^3} \quad \ldots\ldots(32)$$

Since the coefficient b of cubical expansion is three times a, the coefficient of linear expansion, equation (32) can also be written:

$$\rho_1 \propto \frac{\sqrt{m}\,a(1 + 3a\theta)\theta^{\frac{1}{2}}}{N_0 e^3} \quad \ldots\ldots(33)$$

Equation (33) is of the form

$$\rho_1 = K\,(\theta^{\frac{1}{2}} + b\,\theta^{\frac{3}{2}}) \quad \ldots\ldots(34)$$

where K is a constant and b is the cubical coefficient of expansion of the metal. It is here assumed that this coefficient is reckoned from the absolute zero of temperature, and that the metal expands by a linear law. Then if the volume of a liquid metal is $V_{\theta 1}$ at the absolute temperature θ_1 and V_θ at a lower absolute temperature θ

$$b = \frac{V_{\theta_1} - V_\theta}{V_\theta\theta_1 - V_{\theta_1}\theta} \quad \ldots\ldots(35)$$

From data obtained by Day, Sosman and Hostetter[5] we obtain for the value of the coefficient of lead, $b_{Pb} = 124.1 \times 10^{-6}$, and for tin $b_{Sn} = 103.6 \times 10^{-6}$. We substitute these values in equation (34), and so choose the constant K that the resistivity obtained from equation (34) at the temperature 1000° K. shall be the same as the value obtained by experiment. In doing this we find $K = 3.181$ for lead, and $K = 1.712$ for tin. We then make plots of Equation (34) for lead and tin and obtain the theoretical curves for lead and tin given in the curve sheet Fig. 2. These

[5] "The Determination of Mineral and Rock Densities at High Temperature," *American Journal of Science*, vol. xxxvii, January, 1914.

curves below temperatures where the metals are molten are shown in dotted lines because equation (34) cannot be expected to apply below a point where a metal changes from liquid to solid.

If our theory was faultless the theoretical curves should be straight lines after the metals melt and should have the same slants as the experimental curves. These results are only approximately realized. The experimental curve for lead shows an increase of 0.0455 microhm per degree, while the theoretical curve shows an increase of about 0.066 microhm per degree. The corresponding figures for tin are: experimental, 0.0246; theoretical, about 0.033.

The writer considers that these results indicate that our hypotheses fail to account for all the factors which are involved in a change in resistance with temperature of a molten metal, but that, on the other hand, the general character of the curve confirms more than it discredits the theory in its broad outlines.

It remains to inquire if, according to the above theory, any reasonable explanation can be proposed which will account for the sudden change in resistance which takes place in a pure metal when it melts.

It requires a very considerable input of energy to change a metal from the solid to the liquid state, but the process involves no change in temperature. Thus to convert 1 gramme of Al from solid into liquid requires 77 gramme-calories, Pb requires 5, Sn 14, Hg 3, Cu 43, Bi 13, Ag 22, Zn 28. No relation appears to exist between these various inputs of energy and the change which takes place in the resistivity of the metal when it melts, and according to our hypotheses we must look for the change in resistance as due chiefly to a change, upon fusion of the metal, in the number of atoms which constitute an atomic group. We conceive, as it requires no change in temperature for a metal to pass from solid to liquid, that the energy which must be put into the metal to bring about fusion is used in breaking up aggregations of atoms capable of oscillating together as a group into aggregations consisting of a less number of atoms which oscillate as a group. We may assume also that, in those metals which expand in liquefying, a part of the energy is used in expanding the metal. In other words, the latent heat of fusion is stored when a metal melts as potential energy of separation of its atoms. We may not only think of the atomic groups as consisting of a smaller number of united atoms when the metal is molten, but may con-

sider that these groups are free to wander about in the fluid metal, and, not being held in fixed relations to each other by attractive forces, that the proportionate number of atomic groups which collide in a given time, and so allow electrons to pass from one to another, is much less in the molten metal than in the solid metal. Further than this it is unprofitable to speculate with our present state of knowledge. Experiment shows us that in most cases the ratio $\frac{\rho_l}{\rho_s}$, namely, the resistivity of the metal just after fusion to its resistivity just before fusion, is about 2 when the metal expands on liquefying and about ½ when it contracts on liquefying.

To a certain extent we can express these ideas in symbolic form by making use of equation (29).

Let $\rho_l \propto \frac{(d-\rho)\sqrt{m}}{N\rho^3 e\theta^{\frac{1}{2}}}$ express the resistivity of the metal just after fusion. We know that when the metal gives up its latent heat of fusion and becomes solid at the same temperature there is no reason to suppose that the quantity e changes. Since d is the distance between centres of atomic groups we should expect d to change, becoming less, due to an increase in density of the metal, and larger due to the assumed fact that the atomic groups of the solid metal are larger and hence have their centres further separated. We should expect ρ, the diameter of an atomic group, to be larger in the solid, and also m, the mass of an atomic group. The number of atomic groups N in the unit of volume would increase from an increase in density of the metal, but decrease from the assumed fact that each group is made up of an increased number of atoms to the group. Writing a prime mark on those quantities which change, calling ρ_s the resistivity of the metal when solid and ρ_l when liquid, and taking the ratio of ρ_l to ρ_s we have

$$\frac{\rho_l}{\rho_s} = \frac{(d-\rho)\sqrt{m}\, N'\rho'^3}{(d'-\rho')\sqrt{m'}N\rho^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (36)$$

If we further assume that $m \propto \rho^3$ and $m' \propto \rho'^3$, we obtain

$$\frac{\rho_l}{\rho_s} = \frac{(d-\rho)N'\rho'^{\frac{3}{2}}}{(d'-\rho')N\rho^{\frac{3}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (37)$$

As stated above, this ratio is greater than unity in most cases and less than unity in the exceptional cases of antimony and bismuth.

It may be noted that if the solid metal were cooled to the absolute zero we should expect $d' = \rho'$. In this case the ratio becomes infinity, as it should, according to experiment.

The above discussion of the facts of metallic conduction and the hypotheses which have been proposed to account for these facts touches the general problem of electrical conduction in only a few places. The accumulation of experimental evidence is not yet sufficient to make a longer or a more detailed discussion of metallic conduction profitable, and a further discussion of the general problem of electrical conduction, including such topics as the resistivity of insulators, the relations of electrical and thermal conductivity, the subjects of thermal electromotive force, the Peltier effect, the Thomson effect, the Hall effect, thermionics, and the conduction through hot gases at atmospheric pressure, would entirely transcend the purpose and assigned limits of this article.

It is thought that the most sound and fruitful increase in our knowledge of the relation between electricity and ordinary matter will come from an extended experimental investigation and by interpreting and coördinating the facts and phenomena revealed by experiment. This method, in which the characteristic elements of revealed phenomena are mentally abstracted and their essential likenesses and dissimilarities are observed, will do more for the advancement of science than propounding theories to which mathematical expression may be given, especially when logical developments of such theories rest upon assumptions of the existence of conditions essentially artificial.

Palmer Physical Laboratory, Princeton, N. J.,
March 24, 1915.

SOUND STEEL FOR RAILS AND STRUCTURAL PURPOSES.

BY

SIR ROBERT A. HADFIELD, F.R.S.,

Member of the Institute.

[SECOND COMMUNICATION]

SINCE the author contributed his paper on "Sound Steel for Rails and Structural Purposes," which appeared in the February JOURNAL OF THE FRANKLIN INSTITUTE, he has completed the instructions of the Pennsylvania Railroad Company to produce for them one hundred tons of ingots made under his sound steel system. These ingots were made at the works of his firm in Sheffield, full particulars being given in Plate I and Table I. The table gives the analyses of the various ingots, also an exact record as to the cubic capacity of the cavity or sinking head portion at the top of each ingot. So far as the author is aware, there has never before been such careful preparation of a considerable number of ingots to be rolled into rails. The methods of manufacture have been fully described in the previous paper to this Institute and elsewhere, as shown by the accompanying bibliography.

It will therefore be interesting to see how the rails produced from these ingots behave when put to use. It is probable they will give the best results yet obtained in any country, no matter how severe the service may be, because the material from which they are made is perfectly sound, free from blowholes, segregation, and piping. Moreover, the result of this research relating to the question of the soundness and suitability of such steel for producing *safe* rails will be, no doubt, to show that it is possible that by the use of this sound steel rails of the highest quality will be obtained, and this with very little addition, if any, to their cost. In fact, when working on a large scale, it is probable the cost will be reduced.

The joint paper by Dr. G. K. Burgess, of the National Standards Bureau, and the author on "Sound Steel Ingots and Rails," read before the American Institute of Mining Engineers,

also on the same subject read before the Iron and Steel Institute in London, May, 1915, shows the superior quality obtained by the soundness and freedom from segregation of this type of ingot. This was fully borne out in the actual appearance of the rails produced from such ingots for the research in question. It was also noted that the rails broken up and used for test showed superiority in their nature and quality, not only as regards finish, but in their chemical, mechanical, drop, and other tests. All these points are fully set forth in the joint paper above mentioned, and as regards the steel side of the question they are further dealt with by the author in the paper on "Sound Steel for Rails and Structural Purposes," published in the JOURNAL OF THE FRANKLIN INSTITUTE of February, 1915.

To further illustrate these facts, the main observations in the joint research above mentioned are shown in the following remarks, which, it may be mentioned, are statements not made by the author of this paper, but by his collaborator in the previous research, Dr. G. K. Burgess, of the National Standards Bureau, Washington:

REMARKS BY DR. G. K. BURGESS REGARDING THE COMPARISON OF TWO SPLIT INGOTS.

"Ingot 'A,' made under the Hadfield system, is perfectly sound, free from blowholes, piping, and segregation.

"Ingot 'B,' of American make, is unsound and contains blowholes, piping, and segregation."

Ingot "A," cast by the feeding method, was split or sliced open vertically on the axis line, and presents a smooth, clear surface, free from segregation, pipe, seams, blowholes, or other imperfections.

Ingot "B," representing the average ingot, was split open in the same manner and presents the usual piped appearance, nearly one-half being unsound and unsuitable for rolling into rails, whereas the ingot cast by the feeding method is sound throughout.

In other words, a discard of fifty per cent. would be necessary for this comparison ingot "B," and only about ten per cent. in the case of the ingot "A"; that is, there would be but little discard below the feeding head.

A sulphur print taken of one-half of the vertical section of the ingot "A" indicates very uniform distribution of the constituents in the metal, and practically freedom from segregation.

As would be expected, ingot "B," with its pronounced pipe, shows marked segregation of carbon, phosphorus, and sulphur in the piped region to a depth of nearly fifty per cent. from the top of ingot, and other regions of somewhat varying composition. The manganese shows but slight segregation anywhere.

This examination shows the great superiority of the ingots cast by the Hadfield feeding process, such ingots being physically sound and uniform throughout, also free from segregation.

These two ingots were rolled into rails by the Maryland Steel Company, Sparrow's Point, and the following further comparisons are also stated by Dr. Burgess:

Uniform hardness, determined by a large number of Brinell ball hardness tests, is shown over the whole series of rails from the Hadfield ingots, whereas rails from the ordinary ingot do not possess this uniform quality.

The "A" rail from the Hadfield ingot is sound—beautifully so—right up to the front end or to the "bloom crop" itself. The ordinary ingot is unsound at the same portion of the ingot.

The web, which is usually the part consisting of the poorest material, is practically uniform in the case of the Hadfield ingots with the remainder of the section.

Examination of the rails shows that the ingots made by the Hadfield process will give rails of uniform quality, free from flaws of all kinds.

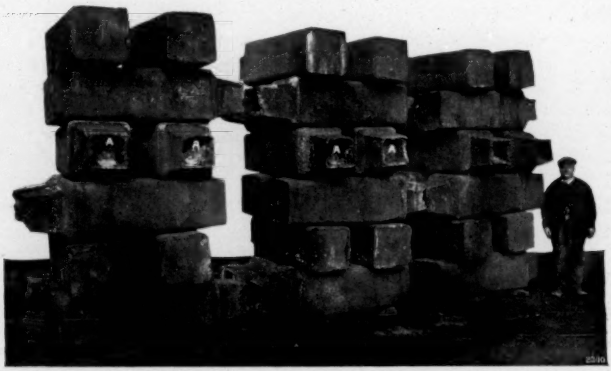
Drop tests on the rails from the Hadfield ingots show a high degree of uniformity of resistance to shock.

The above independent examination and observations by Dr. Burgess are a remarkable confirmation of the statements made by the author during the last few years with regard to the advantages obtained by the use of sound steel.

A proof of this soundness is shown in Table 1, column 10, headed "Capacity of cavity," in which is set forth the amount of cavity in the head of each of the ingots cast by the Hadfield system. A further description of the nature of this cavity was

given in the JOURNAL OF THE FRANKLIN INSTITUTE of February, pages 110 to 140. It is also still more clearly described in Plate II now given, also at "A" in Plate I accompanying this paper. Column II of Table 1 gives the same information worked out in percentage figures. The uniformity of these ingots is shown by this means in a remarkably clear manner; also that each ingot is perfectly sound, free from blowholes, with no piping and no

PLATE I.



Thirty-six 18-inch rail ingots, weighing about one hundred tons, made for the Pennsylvania Railroad. 5 feet 4 inches in length. Weight, 5380 pounds each.

These ingots have been made under the Hadfield system of producing sound steel.

Each of these thirty-six ingots is sound, entirely free from blowholes, segregation, or piping. After cutting off about 10 per cent. of the ingot, the whole of the remainder of the steel is available for producing perfectly sound rails. Fuller particulars of the exact amount of settling as represented by the cavities *A* for each of these thirty-six ingots is shown on the accompanying Table 1. The average capacity of the cavity for each ingot is 9943 cubic centimetres,—that is, 3.19 per cent. of the weight of the ingot. The weight of the fluid steel which has passed from the head portion into the ingot itself is about 130 pounds. In ordinary ingots the greater part of this material remains in the upper portion of the ingot and does not feed the piping or settling which occurs, whereas in these ingots this takes place, enabling the extraordinary soundness mentioned to be obtained.

segregation below about ten per cent. discard; in fact, even with eight per cent. discard the segregation is practically of no importance. Ordinary ingots for rails or other purposes show no such cavity, and it is quite impossible to determine from the outside portions of the ingot whether it is good or bad. In every ingot made under the writer's system it is possible to know that it is good. If for any reason a bad heat has been used, then an

TABLE I.

Ingots Made for the Pennsylvania Railroad by the Hadfield System of Producing Sound Steel.

Ingot No. and mark.	Heat No.	Analysis					Head particulars			
		C	Si	S	P	Mn	Height to which filled in head, inches	Depth of settling, inches	Capacity of cavity, c.c.	Percentage of settling to total bulk of ingot
1	2	3	4	5	6	7	8	9	10	11
1	4588	.64	.10	.047		.97	13	7½	8,930	2.86
2	4600	.65	.15	.049		.96	13½	8½	9,825	3.16
3	4615	.64	.20	.048		1.01	14½	7	9,000	2.89
4	4627	.64		.052		.97	14	8½	9,600	3.08
5	4641	.67 .69		.045		.94 .92	14½	8½	9,000	2.89
6	4653	.61		.053		.85	13½	7½	9,900	3.17
7	4668	.58		.042		.93	14½	8½	10,100	3.24
8	4680	.65	.14	.049	.029	.92	13½	8½	10,250	3.29
9	4696	.66		.038		.96	13½	6½	8,600	2.77
10	4709	.58		.049		.93	13	7½	8,930	2.88
11	4723	.63		.044		.95	13½	8	9,900	3.17
12	4738	.63 .64		.042		.91	13½	9	10,300	3.31
13	4761	.65		.048		.90	13½	8½	10,800	3.47
14	4774	.65		.040		.94	14	8½	9,950	3.19
15	4801	.66		.036		.95	13½	8½	9,150	2.90
16	4813	.64	.14	.048	.032	.93	14	8½	10,800	3.45
17	4825	.66		.045		.92	13½	6½	9,000	2.89
18	4829	.66		.041		.98	14	8½	11,100	3.55
19	4835	.69		.046		.91	13½	7½	9,520	3.05
20	4847	.63 .64		.047		.93	13½	9½	10,450	3.37
21	4861	.62 .61	.21	.045	.031	.92	14	9⅝	10,900	3.49
22	4873	.69		.050		.95	14	9⅝	10,250	3.29
23	4887	.63		.050		.89	14	9	10,500	3.36
24	4908	.64		.041		.84	14	8½	9,750	3.11
25	4915	.65 .66		.049		.02	14	9½	9,675	3.10
26	4939	.63 .64	.16	.045	.028	.92	13	7½	8,800	2.84
27	4978	.67 .68		.051		.96	14½	9⅝	9,260	2.95
28	4992	.66		.045		.94	13½	9½	9,000	2.88
29	5004	.65		.052		.94	14	8¼	10,175	3.27
30	5018	.64	.16	.039	.031	.92	14	8½	10,040	3.21
31	5030	.60		.056		.94	13½	10⅛	11,950	3.82
32	5046	.63 .62		.042		.93	13½	7	10,500	3.37
33	5059	.63 .64		.049		.92	14	8⅞	10,750	3.44
34	5073	.64 .63		.045		.90	14	9½	10,500	3.37
35	5085	.63 .64	.16	.042	.031	.86	13½	9½	11,000	3.52
36	5099	.63 .64		.039		.86	11	8⅞	10,040	3.34
37	4787	.67		.045		.88	13½	7⅜	8,125	2.58 cut up
1	2	3	4	5	6	7	8	9	10	11
Minimum		.58	.14	.036	.028	.84	11	6½	8,600	2.77
Maximum		.69	.21	.053	.032	1.01	14½	10⅛	11,950	3.55
Average		.64	.16	.046	.030	.92	13½	8½	9,943	3.19

The total weight of these ingots amounts to 96 tons.

inspector can detect this in the ingots themselves, either in a hot or cold condition. There is, however, no reason to have any bad ingots of this nature. The steel maker by the preliminary test knows this before he pours the steel.

Plate II represents one of the thirty-six eighteen-inch ingots prepared by the author, taken from the 100-ton lot prepared for the Pennsylvania Railroad. This ingot was sliced for its full length. Its analysis was as follows:

C	Si	S	P	Mn
0.67	0.18	0.045	0.03	0.88 per cent.

This ingot is of perfectly sound structure, and represents the same high quality of each of the thirty-six ingots sent by the instructions of the Pennsylvania Railroad to be rolled into rails. After cutting off about ten per cent. discard the whole of each of these thirty-six ingots can be worked up into sound and safe rails. The same remark would just as well apply to thirty-six million of such ingots!

The capacity of the cavity of the ingot (shown in Plate II) which was cut up, and at the part marked "A," was 8125 cubic centimetres, the percentage of settling to the total weight being 2.58 per cent. The weight of material which passed from the head portion into the ingot itself was about 130 pounds. It is exactly this portion of the fluid steel being properly applied, that is acting as feeding material to the body of the ingot, which makes the difference between ordinary and these special ingots.

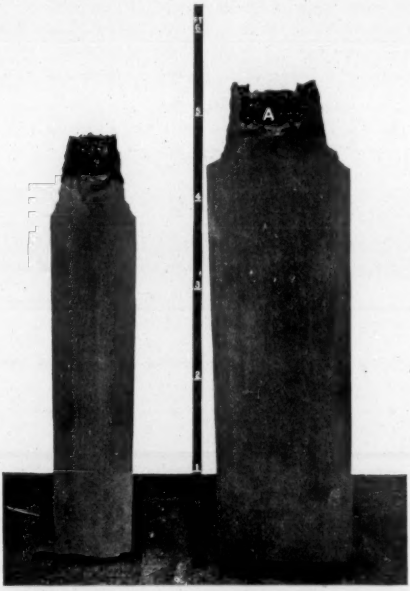
This ingot was selected because it showed the lowest cavity percentage of the series. The slight variations in the percentage of settling, and therefore difference in the cavities, are of no importance. For example, the sand heads may vary slightly in height, or the steel may not be poured to just the same height. In such cases the ingots with the shortest length of head will necessarily have the smallest capacity. Nevertheless, as the figures show, the average percentage of the cavity is remarkably uniform.

In ordinary ingots, even of piping nature, probably not more than one-third of the fluid steel at the top or upper portion passes into the body of the ingot, consequently it is quite easy to understand why unsound and piped places, also general looseness of structure, occur for a long way down the ingot. This is the secret of the reason why it is necessary in such ordinary ingots to

have discards varying from thirty per cent. to forty per cent., and in some cases even more, in order to get rid of unsoundness,

PLATE II.

FIG. 1. FIG. 2.



Ingots made under the Hadfield system of *producing sound* steel.

11-inch mild steel ingot.

Heat No. 4952/3194 of the following analysis:

C.	Si.	S.	P.	Mn.
.18	.06	.044	.031	.88

18-inch ingot.

Heat No. 4787/3191 of the following analysis:

C.	Si.	S.	P.	Mn.
.67	.18	.045	.03	.88

Sliced open upon the full transverse length.

This ingot is representative of the 36 ingots sent to be rolled into rails. The capacity of the cavity of this ingot at *A* was 8125 cubic centimetres, and the percentage of "settling" to the ingot was 2.58.

piping, and segregation; whereas in the ingots made on the writer's plan only about eight or ten per cent. is necessary.

Plate I shows the thirty-six eighteen-inch ingots, five feet four inches in length, weighing about 5380 pounds each, made for the Pennsylvania Railroad. Each ingot is perfectly sound and free from blowholes, segregation, or piping, and no less than about ninety per cent. of this material is available for producing perfectly sound billets. The exact amount of settling as represented by the cavities, marked "A," is given in full for each of the ingots in Table 1. The average capacity of the cavity for each ingot is 9943 cubic centimetres; that is, 3.19 per cent. of the weight of the ingot. In each of these ingots about 140 pounds of the fluid steel pass into the body of the ingot.

TABLE 2.

Analysis of Samples Taken from Ingots Made by the Hadfield System for Producing Sound Steel Free from Porosity, Piping, and Segregation.

The following analyses were taken from the ingots referred to in the table given below. In this case the discard from each ingot was fifteen per cent.

All the ingots were made under government inspection. The following are the analyses by the government chemist:

Heat Nos.	C	Si	S	P	Mn
	Billets for small-calibre projectiles.				
S. 1277	.37	.17	.042	.032	.90
S. 1278	.36	.19	.032	.030	.85
S. 1298	.39	.22	.030	.032	.84
S. 1299	.36	.22	.029	.029	.86
Maximum	.39	.22	.042	.032	.90
Minimum	.36	.17	.029	.029	.84
Average	.37	.20	.033	.030	.86
	Billets for small-calibre projectiles.				
S. 1153	.39	.17	.033	.040	.95
S. 1154	.39	.15	.036	.040	.89
S. 1155	.37	.24	.038	.040	.94
S. 1156	.38	.18	.034	.045	.89
S. 1157	.40	.20	.034	.044	.93
Maximum	.40	.24	.038	.045	.95
Minimum	.37	.15	.033	.040	.89
Average	.38	.19	.035	.042	.92

TABLE 2.—*Continued.*

Heat Nos.	C	Si	S	P	Mn
	Billets for large-calibre projectiles.				
S. 1322	.42	.20	.040	.037	.86
S. 1321	.44	.17	.041	.036	.87
S. 1320	.49	.20	.038	.036	.87
S. 1309	.39	.23	.036	.031	.77
S. 1308	.50	.21	.033	.031	.80
S. 1307	.40	.22	.033	.031	.86
S. 1306	.49	.19	.033	.032	.85
S. 1305	.46	.24	.034	.032	.86
S. 1304	.51	.18	.036	.031	.83
S. 1303	.45	.25	.036	.031	.86
S. 1301	.36	.21	.035	.025	.83
S. 1300	.38	.21	.034	.025	.81
S. 1289	.38	.25	.040	.034	.89
S. 1288	.43	.15	.039	.029	.84
S. 1284	.41	.24	.036	.032	.83
S. 1281	.44	.26	.034	.030	.92
S. 1280	.39	.18	.036	.029	.87
S. 1269	.42	.16	.040	.034	.86
S. 1268	.40	.19	.036	.033	.86
S. 1267	.36	.21	.035	.032	.86
S. 1266	.41	.17	.040	.034	.84
S. 1265	.34	.18	.030	.027	.83
S. 1263	.43	.17	.037	.032	.86
S. 1252	.42	.25	.031	.031	.85
S. 1251	.34	.19	.045	.030	.83
S. 1250	.46	.18	.034	.033	.89
Maximum	.51	.26	.045	.037	.92
Minimum	.34	.15	.030	.027	.80
Average	.42	.21	.038	.032	.86

The remarkable uniformity of these ingots is shown. The whole of them were worked into projectiles in which not a single waster projectile resulted.

Plate III is of interest, as it shows the application of the system to the production of mild steel ingots containing only 0.18 per cent. carbon. The ingots for rails as shown in Table 1 contain an average of 0.64 per cent. carbon. This system is equally applicable to any kind of steel, whether plain carbon or alloy steel.

As further showing the quality of ingots made under this system, Table 2 gives analyses of samples taken from ingots in which a discard of fifteen per cent. was cut off from each ingot. The ingots were made under government inspection, and the analyses were taken by the government chemist. Table 3 gives the same information as regards another set of ingots in which twenty-five per cent. discard was cut from each ingot.

This particular experiment enables comparison to be easily drawn between ingots having (*a*) fifteen per cent. and (*b*) twenty-five per cent. discard. It will be seen that the analyses show that the material from the ingots with fifteen per cent. discard is fully equal to that with twenty-five per cent. discard; that is, with the lesser percentage there is no segregation. These

PLATE III.

particular ingots were used among many thousands for the manufacture of high explosive projectiles. The resulting projectiles were equally as good from the billets with fifteen per cent. as those made from twenty-five per cent. discard; that is, there was not a single waster in either case. Even with billets made from ingots with only ten to twelve per cent. discard the results would

have been the same as obtained with fifteen per cent. discard. In other words, perfectly sound steel can be obtained with ten to twelve per cent. discard. In any case, even with fifteen per cent. discard, there is a great saving in material, loss of time, and the avoidance of remelting a large percentage of the ingot, as is now the case. It may be mentioned that from ingots made in the ordinary manner about forty per cent. is insisted upon, and this rightly so.

TABLE 3.

Analyses of Samples Taken from Ingots Made by the Hadfield System for Producing Sound Steel Free from Porosity, Piping, and Segregation.

The following analyses were taken from the ingots referred to in the table given below. In this case the *discard from each ingot was twenty-five per cent.*

All the ingots were made under government inspection. The following are the analyses by the government chemist:

Heat Nos.	C	Si	S	P	Mn
	Billets for small-calibre projectiles.				
S. 1213	.40	.18	.036	.032	.89
S. 1237	.38	.24	.035	.035	.89
S. 1238	.37	.24	.033	.035	.89
S. 1294	.39	.19	.036	.036	.84
S. 1295	.40	.26	.039	.035	.92
S. 1330	.39	.24	.036	.035	.86
S. 1331	.41	.19	.035	.032	.84
S. 1354	.37	.24	.038	.032	.92
Maximum	.41	.26	.039	.036	.92
Minimum	.37	.18	.033	.032	.84
Average	.39	.22	.036	.034	.88
	Billets for small-calibre projectiles.				
S. 1257	.40	.20	.033	.034	.88
S. 1259	.40	.20	.030	.034	.87
S. 1270	.40	.19	.041	.034	.86
S. 1271	.41	.22	.037	.032	.91
S. 1272	.41	.20	.035	.033	.86
S. 1273	.39	.27	.039	.037	.89
S. 1274	.38	.25	.042	.037	.91
S. 1275	.42	.20	.042	.037	.90
S. 1276	.40	.21	.042	.035	.91
S. 1279	.38	.21	.036	.036	.93
S. 1290	.41	.21	.034	.035	.88
S. 1291	.42	.26	.036	.035	.91
S. 1292	.40	.24	.036	.039	.87
S. 1293	.41	.24	.039	.037	.84

TABLE 3.—*Continued.*

Heat Nos.	C	Si	S	P	Mn
	Billets for small-calibre projectiles.				
S. 1310	.40	.26	.037	.037	.91
S. 1311	.40	.23	.035	.040	.92
S. 1312	.40	.23	.034	.033	.92
S. 1313	.39	.23	.032	.034	.92
S. 1314	.40	.19	.034	.036	.92
S. 1315	.39	.22	.036	.032	.87
S. 1316	.40	.21	.036	.033	.91
S. 1317	.39	.26	.038	.033	.93
S. 1318	.40	.21	.038	.033	.93
S. 1319	.38	.22	.037	.035	.90
S. 1337	.38	.28	.034	.030	.89
S. 1338	.40	.25	.034	.032	.84
S. 1339	.39	.22	.035	.032	.90
Maximum	.42	.28	.042	.040	.93
Minimum	.38	.19	.030	.030	.84
Average	.40	.23	.036	.035	.89

The remarkable uniformity of these ingots is shown. The whole of them were worked into projectiles in which not a single waster projectile resulted.

To work out this great improvement in definite figures, taking 100 tons as the basis, then from

(*a*) Ingots made in the ordinary manner there would be obtained about sixty tons of sound steel; that is, forty per cent. discard.

(*b*) Under the writer's method, with twenty-five per cent. discard there would be seventy-five tons of sound steel.

(*c*) Under the writer's method, with fifteen per cent. discard there would be eighty-five tons of sound steel.

(*d*) Finally, as above mentioned, with ten to twelve per cent. discard there would be about ninety tons of sound, usable product, a saving of no less than thirty tons as compared with ingots under "A"; that is, made in the ordinary manner.

To sum up the foregoing, if eighty-five to ninety tons of safe, usable material of the highest class can be obtained from 100 tons of ingots, what is the use, as at present practised, in making

our steel furnaces produce ingots which require thirty to forty per cent. discard, when by using the system now referred to ten to twelve per cent. discard is quite safe and gives products of the highest possible value?

The world's output of steel for 1913 was estimated to be 75,000,000 tons. If a probable average waste of, say, twenty-five per cent. can be reduced by one-half, then a total of no less than 10,000,000 tons can be saved. This represents a value of probably not far short of $200,000,000, or the same furnaces now engaged in what are practically remelting operations can be turned on to producing a further supply of steel for other purposes. Besides, there is the considerable saving effected of avoiding loss of oxidation, both in the melting and subsequent reheating furnaces—this in itself a great waste which is absolutely unnecessary.

By the use of the system now described not only are the qualities of the ingot greatly improved, but these at once make themselves felt in the superior product obtained when rolled or forged. When producing billets from ingots cast by the ordinary method to be used for projectiles,—that is, from ingots not cast by the sound method,—the working results in actual practice show no less than 6.2 per cent. of waster projectiles owing and due to the defects in the material arising from those which originally existed in the ingots. Upon exactly the same nature of products,—that is, projectiles, from ingots made by the sound steel method, including the feeding arrangement,—the wasters were reduced to the low figure of only *1.4 per cent.* Wasters owing to seams, roaks, and other causes were therefore reduced from 6.2 to 1.4 per cent., a reduction of no less than 4.8 per cent.; thus on every 10,000 projectiles obtained from ordinary ingots there would be a saving of no less than 480 projectiles.

In a large daily output of steel it will be understood that this system enables a very important saving to be obtained, not only in reducing the discard and avoiding loss of material, but, as will be seen from the foregoing facts, by shortening the time of output.

In addition, there is an enormous saving effected by the discard being reduced from forty per cent., which is insisted upon for ordinary ingots, to only fifteen per cent. from ingots made

under the author's system. In other words, while projectiles produced from ingots made in the ordinary way require, say, 1000 tons of ingots, under the author's system only 750 tons of ingots are required to produce the same number of projectiles. This represents a saving of no less than 250 tons of ingots.

TABLE 4.

Table Showing the Time Occupied in Tapping and Casting Twelve Heats from a Fifteen-ton Open-hearth Furnace (Acid) into Ingots Made by the Hadfield System of Making Sound Steel.

Size of ingots, 11 inches.

Heat No.	Time occupied opening tap-hole		Time running into ladle		Time occupied from dropping spout to casting first ingot	Time occupied from commencing to cast first ingot to finish of cast		Number of ingots cast	Total weight of ingots cast	Total weight of ingots cast
	Min.	*Sec.*	*Min.*	*Sec.*	*Sec.*	*Min.*	*Sec.*		*Tons*	*Pounds*
S. 1476 A	4	0	3	45	15	22	10	21	16	36,000
S. 1477 A	4	30	4	0	12	22	0	22	17¼	38,500
S. 1478 A	4	15	3	50	12	22	58	21	16	39,900
S. 1479 A	4	0	4	5	12	22	18	21	16¼	36,300
S. 1480 A	4	10	3	48	12	22	14	21	16	35,900
S. 1481 A	4	0	4	10	11	24	3	22	16¾	37,800
S. 124 B	4	0	4	15	12	23	0	21	16¼	36,200
S. 125 B	5	10	4	8	11	23	8	21	16¾	37,700
S. 126 B	4	8	3	50	12	22	50	21	16¼	36,200
S. 127 B	4	0	3	55	12	22	10	21	16	36,000
S. 128 B	4	30	4	0	12	22	12	21	16¼	36,200
S. 129 B	4	10	3	46	12	22	55	22	16¾	37,700
Average..	4	40	3	56	12	22	30	21	16½	36,600

1. Each of the sand heads was dried separately by means of hot coke taken from ladle previously used for ladle heating.

2. Size of nozzle in casting ladle, 1¼ inches diameter.

3. Each of these 11-inch ingots weighs ¾ ton (1700 pounds).

4. One sand head lasts at least six heats; that is, will make 4½ tons (10,000 pounds) of steel before being worn out.

5. One youth makes 21 sand heads in seven hours. It will be seen, therefore, that one youth can make in seven hours sand heads equivalent to 126 ingots, or, say, 20 per hour.

6. By machine-moulding these sand heads the time required for their production could probably be reduced to one-fifth that now occupied.

7. It is specially important to mention that the ingots should not be run too fast. This, of course, depends not only on the size of the nozzle, but how the stopper is lifted or handled.

The use of this system would not only give superior rails, but enable the quantity of what are known as "first class" rails to be increased, and those termed "second class" to be reduced to practically *nil*.

Table 4 shows the full particulars of twelve fifteen-ton heats of open-hearth steel cast into ingots made by the Hadfield system. The steel in question contained 0.40 per cent. carbon; otherwise it was the same quality as that referred to as used for rails. Plate IV shows the casting operation, and Plate V after the casting had taken place. From these photographs it will be seen there is nothing complicated about the application of this system; in fact, the author has personally seen heats cast in which, if it had not been known the system was being used, the differences in time of handling as compared with ordinary steel would not have been detected. Beyond the preparation of the heads, the cost of which has been reduced to some twenty to thirty cents per ton, and assistance in the casting pit, it would be difficult to determine ordinary heats were not being poured. In other words, one of the great advantages of the system is that there is nothing complicated or expensive about either applying or carrying it into operation.

Table 4 gives the actual time occupied in casting, also data referring to the time of making and drying the sand heads. From the figures given it will be seen this operation presents no special features.

No doubt the preparation of the sand tops for a large output could be carried out by machine moulding, when their cost would be reduced to only a few cents per ton.

The sand heads are made to serve from four to eight heats, the only attention required being some slight patching up. The general cost of applying the system on a large scale would probably not be more than about twenty-five to thirty-five cents per ton. Moreover, this is recovered many times over by the much better quality and greater weight of steel obtained.

It may be added that the time required for casting a heat of ingots as compared with those made in the ordinary manner is about the same. The only labor necessary is one teamer and two ingot pit men. The total time occupied in a fifteen-ton heat the author recently saw cast was only about eighteen minutes. The

PLATE IV.

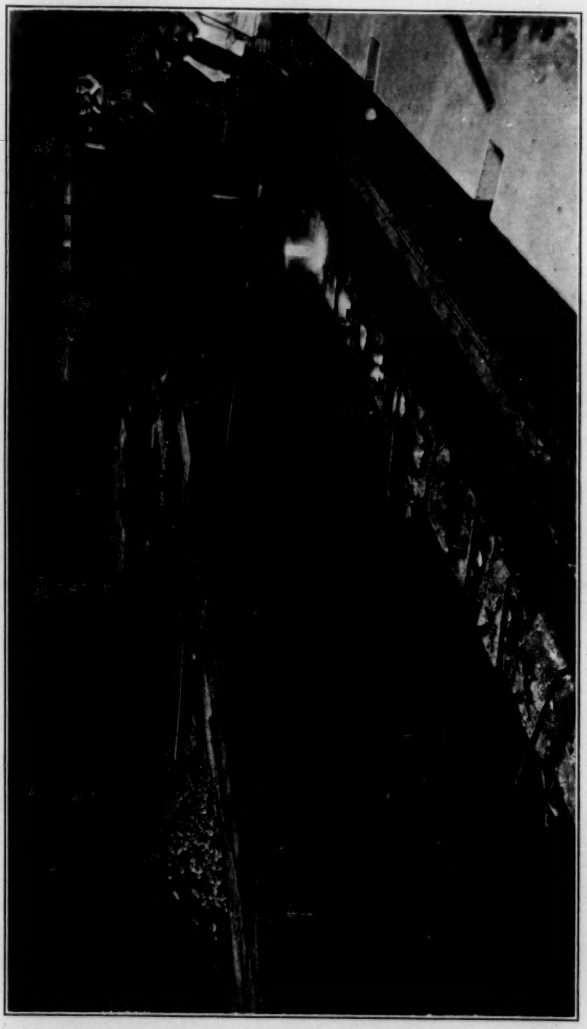
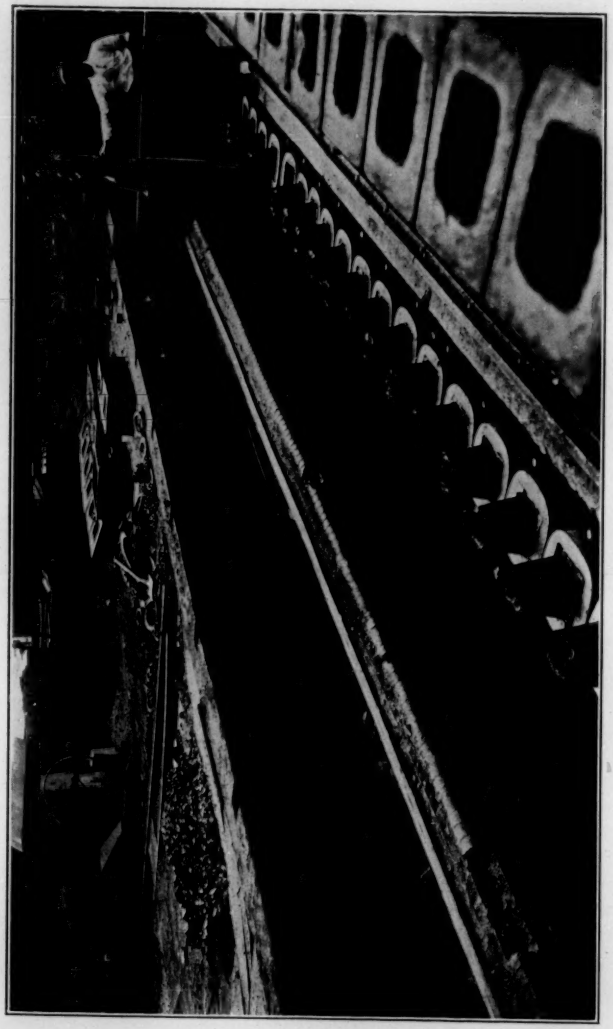


PLATE V.



regularity and uniformity of quality of such ingots are remarkable.

About 70,000 tons of ingots have been produced by this system. The remarkable soundness and cleanness of the steel so obtained have been invaluable in the production of projectile and other work.

To show how important the solution of the problem of sound steel is in America, the following statement has been officially made regarding the serious breakages met with on American railways:

> "Broken rails have caused 2762 accidents during that period (twelve years), resulting in death to 175 persons, injury to 6000, and property damage aggregating $3,237,792; on one railway alone there were 2760 rail failures during the months of November and December, 1911, and January, 1912; the number of rail failures which occur on railroads of the United States is constantly increasing."

There is no need, therefore, to offer any excuse for once more emphasizing how important it is that a thorough test should be given to methods which offer the production of sound steel for rails and other purposes.

The author takes this opportunity of offering his most cordial thanks to the Hon. W. C. Redfield, U. S. Secretary of Commerce, for the interest he has shown and for the assistance he has so kindly rendered on several occasions in granting facilities for carrying out important tests in this matter of sound steel; in fact, the particular lot of ingots described in this paper owes its origin to his desire that tests on rails made from sound ingots should be carried out on a large and practical scale. This friendly help will surely bring about improvements in practice which will add to the safety of the American travelling public. If more such friendly assistance were shown by the official heads of government departments in other countries, much quicker and greater advances in the practical application of science and industry, with consequent advantage to the public generally, would be found to follow.

A STUDY OF SOME CURIOUS PAINTING PHENOMENA.*

BY

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Member of the Institute.

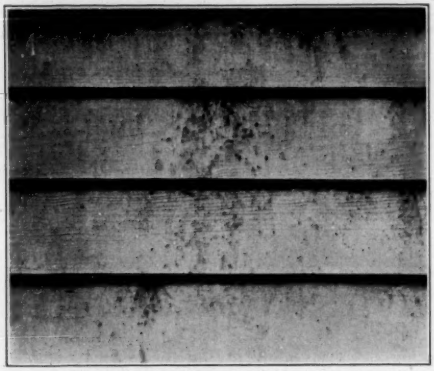
Mildew and Its Prevention.

UPON a recent trip to New Orleans the writer's attention was called to several structures, the beauty of which was marred by fungous growths which were referred to by the painters as mildew. The condition was not universal, but appeared to prevail upon certain types of paint. Upon such paints it was found to be most severe in the sections which were shaded by trees or in partially-sheltered nooks where dampness would be maintained for a considerable period of time. If a window shutter had remained fastened back against the side of a dwelling for a month or so, the covered surface, upon inspection, would be found several shades darker than the rest of the house, many dark mildew spots being exhibited. The under sides of veranda roofs, as well as porch columns, also suffered severely in the same respect. It was quite apparent that the paint had in such instances remained soft or become softened by the action of moisture, thus presenting a surface to which adhered insects, cobwebs, and various organic substances carried by the wind. Since many of the streets of the city contained dust which may have originally been part of canal or river bottoms, it is quite apparent that much decayed animal or vegetable matter could be entrained by soft paint, thus supplying the spores responsible for fungous growths. Structures painted for several years with yellow paint seemed especially subject to fungus. It was found that the custom at one time was to use a colonial yellow for the body of houses, this paint having been prepared from carbonate of lead, using ochre as a tinting material. Recent experiments [1] have shown

* Communicated by the Author.

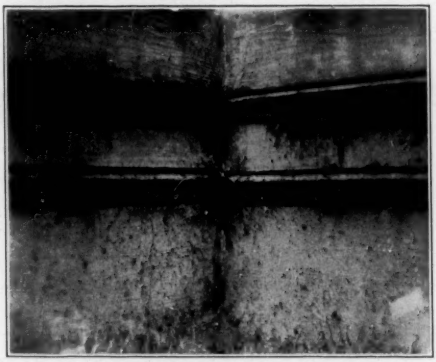
[1] Report of Sub-Committee X on Inspection of White Paint Test Fence at Washington, D. C., *Proc. A. S. T. M.*, vol. xiii, part i, pp. 287–311.

FIG. I.



Section of dwelling showing growth of "mildew."

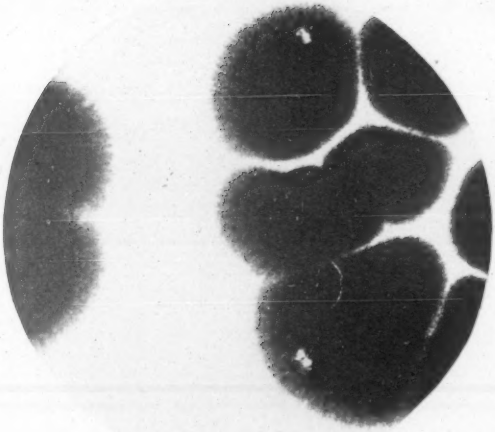
FIG. II.



Appearance of painted surface marred by fungous growth.

that lead paints mixed with inert or silicious pigments never dry properly and are subject to great darkening, caused by the retention of dust particles.

FIG. III.



Species of green Penicillium obtained from mildew on painted surface

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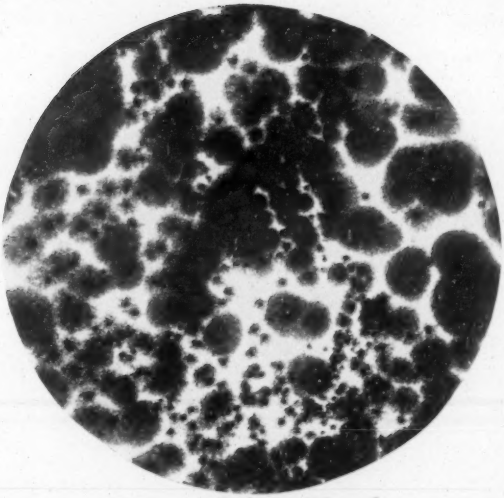
FIG. IV.



Species of Penicillium (olive green). (See text.)

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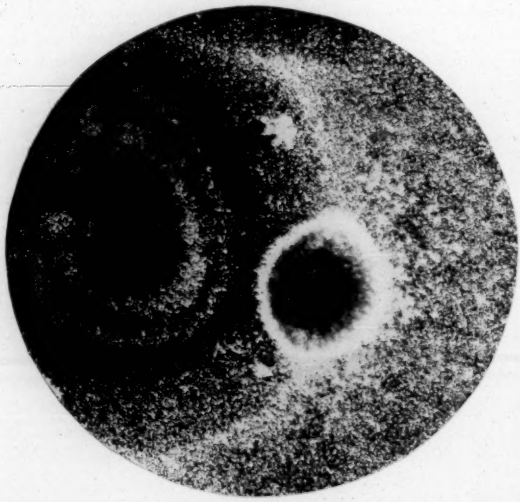
During the inspection trip sections of painted surfaces showing marked formation of "mildew" were collected on lead-coated structures at Hearstville Levee, Carrollton, St. Charles Avenue, Bayou St. John, and other outlying points of the city. In some instances the mildewed surfaces were lightly scraped with a clean knife, the darkened scrapings being collected in a special envelope. Small pieces of wood with the fungus intact were also removed. For the purpose of examining these specimens, it was thought advisable to prepare a culture medium which would exert an inhibitory action upon ordinary bacteria which might be present upon the specimens but which would allow the rapid propagation of the fungous spores. Since cypress is one of the most important woods used for construction purposes, especially in the South, a cypress decoction was decided upon. This was prepared in the following manner, from a section of cypress wood obtained in New Orleans: Fifty grammes of finely-divided wood shavings were boiled in a half litre of distilled water. The decoction was filtered and 1½ per cent. by weight of thread agar was added. After steaming to obtain solution, the mass was filtered, tubed, and sterilized at 120° C. for fifteen minutes.

The infected paint specimens were embedded in the melted special agar placed in Petri dishes. The spores scraped from some of the infected areas were dusted upon the surface of set agar in similar dishes. These were placed in an incubator arranged with an electric thermostat set at 37° C. At the end of periods ranging from twenty-four to ninety-six hours marked growths developed on every plate. The moulds grown in this manner were of mixed types. The various kinds of fungi were isolated, and pure cultures were grown on agar in test-tubes, subsequently plating out the different species in Petri dishes. Some of these are shown in Figs. III to VI. The colors shown by the halftones are not exactly representative. Figs. VII to IX show their appearance under the microscope. Since the staining of fungi is a very difficult operation, some trouble was experienced in preparing slides for examination and photomicrographic record. It is felt, however, that those shown are fairly representative of some of the various species grown.

The two principal types of fungi which were developed from the mildewed surfaces were shown to be species of Aspergillus

and Penicillium. In order to determine the relative resistance of these fungi, small sections of the specimens on agar were placed on painted boards which were kept in a chamber at a temperature favorable to their growth. In this test the black Aspergillus present proved most hardy, the others seeming dormant unless kept constantly moistened. In one test the black mould in a week's period exerted a most destructive effect upon a board coated with

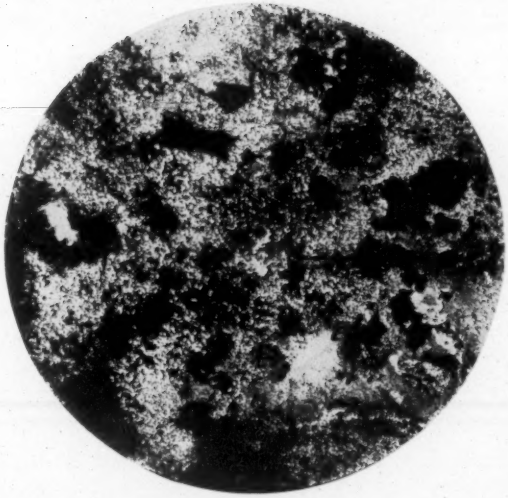
FIG. V.



Species of Aspergillus (black) with spot of Penicillium (green) in centre. The effect of this fungus on painted surfaces is shown in Fig. X.

white lead in oil. Apparently the oil served as a most favorable medium for its development, thus playing one of the leading rôles in the reactions which resulted in the destruction of the paint and exposure of the wood. This action is recorded in Fig. X. The development of the fungi in every instance was much more rapid upon paint coatings which were soft and subject to retention of moisture. Paints which presented a firm, hard, moisture shedding surface resisted the fungi and prevented germination of the

FIG. VI.



Species of green Penicillium that has developed yellow pigmentation in media.
(Yellow undercolor not shown in plate.)

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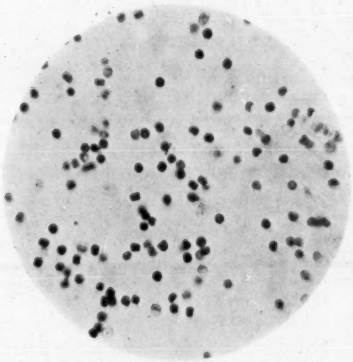
spores. The board tests were then duplicated by floating the painted specimens inoculated with fungi upon the surface of water contained in a tank. The same comparative results were obtained. The paints which dried with a soft, tacky film were prepared from white lead. Those which dried to a hard, resistant film were composite paints containing white lead and zinc oxide. From twenty-five to fifty per cent. of the latter pigment was used to produce a resistant film. The oil used in all paints was linseed oil, to which was added five per cent. of liquid drier. Although it is possible that the absence of "smuts" on

FIG. VII.



Spores of the green Penicillium. × 1400.

paints containing zinc oxide may be due to the formation in the paint film of a zinc salt which acts as a powerful fungicide, the writer is inclined to believe that the real value of the zinc is to be ascribed to its film-hardening characteristics. The addition of turpentine is also to be advised, since more rapid oxidation and firmer films are obtained.

It is customary for the lumber mills in some sections of the South to float the timber in adjacent ponds previous to sawing. These ponds sometimes contain dirty water filled with decayed vegetable matter and covered with colored scum. It is possible that various substances favorable to fungous growths are thus

soaked up by the wood. When cut, used as siding, and painted, these substances may be leached out on some occasions. It is possible that this effect would be prevented by treating new lumber with a coat of zinc chloride solution previous to painting. The writer's tests indicate the high fungicidal value of such treatment. It is likely, however, that the use of hard-drying, dust-resisting paints would prevent the growth of fungi which might be present on the wood used. Before leaving the subject of mildew, it is of interest to quote from the findings of G. Massee,[2] who records a peculiar pink-colored fungi growing on white lead paint in a conservatory:

> "*A New Paint-Destroying Fungus.*
>
> (PHOMA PIGMENTIVORA, MASSEE.)"
>
> "Among the most remarkable of fungi is one that elects to grow on fresh paint. It flourishes in the greatest profusion in hot-houses, its development being apparently favored by a high temperature and constant humidity, as it is but rarely observed on paint elsewhere. About a month or two after a hot-house has been painted, more especially if white paint has been used, numerous small, pale rose-colored specks appear on the paint; these specks gradually increase in size and change to a purple, or sometimes dark red, color, suggesting the idea of blood having been sprinkled over the paint. In course of time the discolored areas extend considerably and form broadly-effused patches several inches across. About a week after the colored patches are fully developed, their surface becomes studded with minute, blackish-red warts. Each wart is a fungous fruit, containing myriads of very minute spores, which in due course are dispersed and start new points of infection.
>
> "When the spores of the fungus are sown on a streak of wet white paint, a faint roseate tint appears in about a week's time, and within three weeks fruit is produced in abundance, and the deep purple characteristic blotches are well developed. Spores sown on a thin

[2] Royal Botanic Gardens, Kew, *Bull. of Miscel. Information*, 1911, London.

smear of pure linseed oil germinate as readily as in paint, but the mycelium remains colorless, and, so far, no fruit has been produced. The result is the same when the spores germinate in ordinary nutritive media or in water. No germination takes place when the spores are sown on a streak of pure white lead or carbonate of lead (pigment). Hence this substance alone is not a suitable medium for the growth of the fungus, although its presence is necessary to enable the plant to complete its normal course of development, and it is also the constituent from which the fungus produces as a by-product the purple-red coloring matter, which is collected in oily-looking drops within the cells of the mycelium, the cell-walls themselves remaining colorless. The red color suggests that the white carbonate of lead undergoes some chemical change induced by the presence of the fungus, resulting in the formation of red oxide of lead. This matter, however, requires careful investigation. The presence of two per cent. of carbolic acid in paint completely arrests the development of the fungus. The following is a technical description of the fungus:

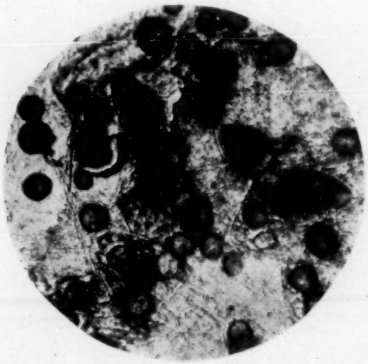
"'Phoma pigmentivora, Massee. Maculæ suborbiculares, determinatæ, læte rosaceæ vel rosaceo-purpureæ, 1–8 cm. diametro. Perithecia in maculis laxe gregaria vel confertiuscula, vix prominula, purpureoatra, subglobosa, contextu parenchymatico, ostiolo vix papillato donata, 125–150 u diametro. Sporulæ ellipsoideæ, hyalinæ, 4–6 x 2–2.5u.'"

Washing of Paint Caused by Inferior Oil.

That microörganisms may play an important rôle in the behavior of materials of painting is the conclusion of the writer, based upon recent investigations into the causes of certain painting defects which have been referred to by the painter as saponification or washing. This condition is generally indicated by the appearance of a white deposit at the base of porch columns and by the paint assuming a soap-like condition if rubbed. Although the instances of such actions are rare, an apparent epi-

demic has recently been shown to exist in one community. The writer has made an inspection of the structures where the trouble occurred, collecting samples of the washed paints for analysis. The investigation also included the analysis and examination of the materials used in the paint, including the oil that was mixed by hand with the paste paint. Almost invariably the oil used was found to contain considerable moisture. When a bottle containing the oil was shaken, large numbers of water bubbles would appear and the oil would form a cloudy emulsion. The

FIG. VIII.

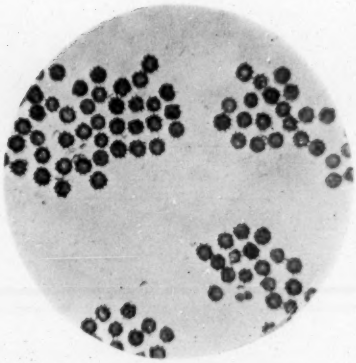


Mycelium and sporangia of the black Aspergillus. × 110.

oil also contained a large percentage of mucilaginous or albuminous matter which is commonly called "foots." In the pressing of flaxseed, the oil is filter-pressed. This, however, takes out only a portion of the suspended matter. After standing a short period of time, certain types of albuminous matter in solution in the oil begin to precipitate out, forming flocculent precipitates which are known as "foots." Improperly filtered oil, that is rushed to the consumer without proper clarification, always contains such impurities. Portions of the foots from the various samples of oil collected were placed upon sterile agar, and in a few days marked growths of a peculiar pink-colored mould were

obtained (see Fig. XI). This mould was identified as a species of Fusarium by V. K. Charles, Assistant Mycologist, Bureau of Plant Industry. Portions of this mould placed upon oil seemed to have a marked effect in changing the constants of the oil, free acid being produced. This result gave a clue to the causes of the washing of paint in which the infected oil was used, and indicated the nature of the intricate reactions which would be occasioned in the drying paint films. The enzymes and micro-organisms in the foots apparently exert a fat-splitting action, the

FIG. IX.



Spores of the black Aspergillus. × 1400.

oil being broken up into glycerine and fatty acids, causing the formation of soap-like products which are acted upon by moisture. The glycerine formed in the film is, of course, non-drying in nature, serving to keep the paint soft and tacky, in which condition it readily attracts moisture from the air. The moisture thus absorbed by the film emulsifies with the soft paint, some of which washes off, depositing upon any convenient surface.

The writer has found that there is no selective action in the washing of the paints; in other words, there is no greater tendency for a lead paint to wash than a zinc paint. This was confirmed by the analysis of the washings piled up at the base of

some hollow fluted porch columns at various residences. Some of the paints applied were made of lead and some of lead and zinc pigments. In every instance lead was found present, zinc being detected in the washings from some zinc-containing paints.

Attention has been brought to the fact that the washing of paint is not of uniform occurrence. It may be noticed upon the porch columns but not upon the body and trim of a house, or it may be noted only upon certain sections of the main structure.

FIG. X.

Effect of black fungi upon soft drying paint.

The writer has observed that in most instances where washing is shown it is generally upon a hollow column or surface, the back of which may hold moisture. It is likely that the moisture stored up in certain places is responsible for starting the complicated reactions which have been previously referred to. It is also possible that the painter, when making up various batches of paint, may use in one batch that portion of the oil which contains the largest quantity of foots and moisture. The section upon which this batch of paint is used would, of course, show the

FIG. XI.

Pink mould growing from "foots" of infected oil.
(Species of Fusarium.)

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greatest amount of washing. That such types of washing are periodical could be explained by the fact that infected seed occurs in quantity only in such years as the flax crop is poor. In the writer's opinion, the prevention of such trouble lies in the use of a well-filtered, perfectly-clarified, moisture-free oil.

"Rusting" or Brown Spotting.

Another painting defect, the cause of which may be traced in some instances to the action of microörganisms or their prod-

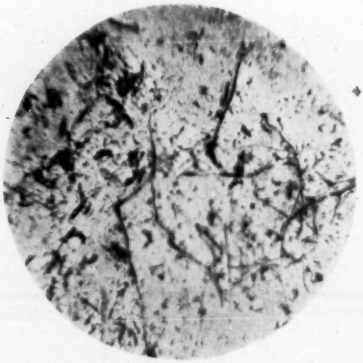
FIG. XII.

Lumber mill showing log pond. (See text.)

ucts, is the so-called "rusting" or brown spotting of paints. This condition is generally noticed upon the ceilings of porches, small brown spots about a quarter of an inch in diameter appearing through the paint film like resin exudations. These spots have an astringent acid taste. This condition, moreover, is generally found upon jobs where the type of washing of paint previously referred to has been recorded, thus indicating that the trouble might be of similar origin. Several of these small, brown-colored spots which appeared upon painted surfaces were recently collected and examined. In some instances these drops were shown by chemical analysis to contain resinous ingredients,

and in other instances metallic substances in combination with organic products. They are generally very soluble in water, yielding rather thick, viscous solutions upon boiling and filtration. When the paint is made of lead, organic salts of lead are found in the solution. If zinc is present in the paint, zinc salts may also be found by analysis. As a result of the investigation, the writer is firmly convinced that the formation of these drops may be traced to two distinct causes. In some instances the soluble matter contained in the wood may be brought to the sur-

FIG. XIII.

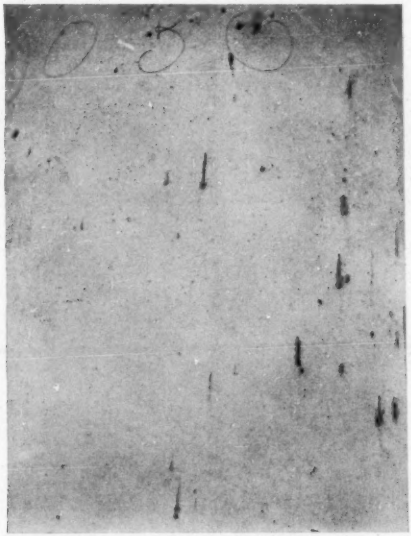


Mycelium and spores of the pink mould. × 1400.

face, exuding at certain places in the paint film and drying up to small, round globules. In certain types of wood there are exceptionally large amounts of soluble constituents which may appear, especially in damp weather and upon surfaces which are not exposed to the sun. Such water-soluble substances apparently have a solvent effect upon the lead and zinc contained in a paint, the compounds formed being deposited upon the surface of the paint in the form of globules. This condition, however, would occur only upon new wood. When wood has been painted for three or four years, it has weathered to such an extent that the water-soluble materials are pretty well leached out. It has

been found, however, that brown spotting occurs most often upon repainting jobs, especially when the oil used in the paint has been of the type examined by the writer, containing moisture and foots of an infected nature. In such cases the hydrolyzing action of the enzymes, which takes place when such oil is used, apparently increases the tendency of the oil to break up

FIG. XIV.

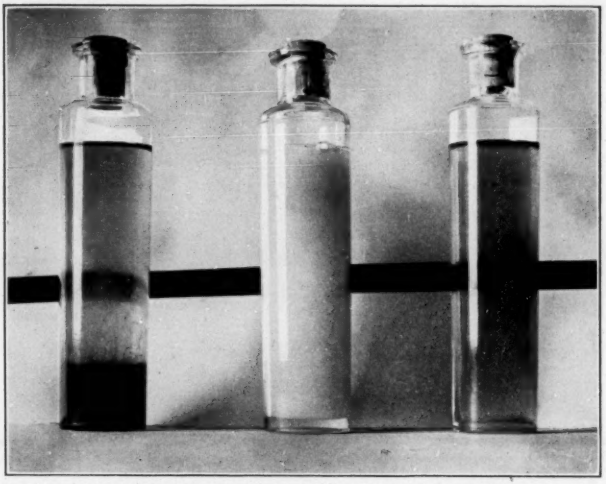


Growth of fungi upon porch column.

into various fatty acids, including formic acid. This has a solvent effect upon the lead and zinc pigments, producing lead and zinc formates which are water-soluble and possessed of an astringent taste. It is therefore likely that such water-soluble metallic compounds, when produced, come as the result of reactions within the oil itself in many instances, and would again indicate the necessity of using properly-clarified oil. The writer

has previously pointed out that proper weathering of new wood before painting will largely do away with the type of spotting that comes from the water-soluble constituents of such wood.

FIG. XV.



Three samples of linseed oil. Black line in back of bottles shows relative clarity. Oil in middle bottle contains considerable moisture and "foots." Oil in end bottle contains a large amount of infected "foots" deposited at bottom.

It is apparent, however, that the selection of satisfactory oil is an even more important consideration, especially upon repainting work.

Immunization of Oils.

Assuming that some types of oil [3] may even be responsible for defects developing in paints while in storage and previous to use, the question of immunization is one worthy of consideration. Although the writer has previously shown that steriliza-

[3] "Changes Occurring in Oils and Paste Paints, Due to Autohydrolysis of the Glycerides," by H. A. Gardner, JOURNAL OF THE FRANKLIN INSTITUTE, May, 1914.

tion of the oil is possible by the application of heat, this procedure may not be feasible in many instances. The same effect, however, may often be produced in the paint mill under ordinary manufacturing processes. It is well known that considerable heat is developed when mixtures of oil and pigments are run through buhrstone mills, the temperature of the paint depending upon the rate of grinding and set of the plates. Temperatures up to 240° F. have even been recorded, and this is more than sufficient for sterilization. It is probable that many oils have thus been rendered harmless, whereas they might have caused trouble had they been mixed cold with hand paddles. Moreover, the hot paste paint as it issues from a mill is in a condensed form, unobtainable by hand stirring. The writer has recently made a study of the chemical phenomena which may result from the storage of such paints in their warm condition. In one instance the hot paste was immediately thinned and canned. In another instance the paste was allowed to cool before thinning and canning. In the latter case the paint proved to be in the most satisfactory condition after storage. When the hot paste is immediately canned, the continued warmth of the product is apt to set up slight hardening with certain pigments. It is probable, however, that the use of a water-cooled spout at the point of exit from the mill plates would sufficiently cool the issuing paste so that storage before canning would not be necessary.

Conclusion: From the previous considerations it is apparent that many painting defects may be prevented through the use of paints of the composite class, based upon white lead pigments but containing sufficient zinc oxide to present a firm, hard film.

When paste paints are thinned by the painter, only clarified, well-settled, moisture-free linseed oil should be used.

The writer wishes to acknowledge the valuable assistance of T. M. Rector in the experimental work.

Physical Properties of Cobalt. H. T. KALMUS and C. HARPER. (*J. Ind. Eng. Chem.*, vii, 6.)—The cobalt examined was reduced from the oxide. The pure metal, containing 99.1 to 99.9 per cent. cobalt, resembles nickel in appearance, but when electro-deposited and polished has a slightly bluish cast. The specific gravity referred to water at 4° C. is 8.7918 at 17° C. for the unannealed metal, 8.8105 at 14°.5 C. after annealing, and 8.9253 at 16°.5 C. after swaging. The Brinell hardness determined in a standard Olsen machine, with a load of 3500 pounds, was about 124 for cobalt cast in an iron mould, that of nickel cast under similar conditions being about 83 and of cast-iron about 102. The presence of 0.06 to 0.37 per cent. carbon had less effect on the hardness of cobalt than slight variations in heat treatment. If the melting-point of nickel be taken as 1452° C., pure cobalt melts at 1478° C. $\pm$ 1.1° C. It has a tensile strength of about 34,400 pounds and a compressive strength of about 122,000 pounds per square inch as cast, the corresponding figures after annealing being 36,980 and 117,200 pounds per square inch respectively. Cast cobalt containing 0.06 to 0.3 per cent. carbon has a tensile strength of about 61,000 pounds, and a compressive strength of about 175,000 pounds per square inch. Both the tensile and compressive strengths are greater than those of pure iron or nickel cast and tested under similar conditions. The reduction of area and elongation are low for pure cobalt, but rise to above 20 per cent. in the case of "commercial" cobalt, 96.5 to 99.6 per cent. Co, containing carbon and other impurities. Pure cast cobalt can be machined in a lathe and, if the casting be cooled under high pressure, can subsequently be rolled or swaged at 500° to 600° C. Commercial cobalt is easily machined and can be rolled or swaged at red-heat without any special preliminary treatment. The specific electrical resistance of cobalt wire of high purity is 89.64×10^{-7} ohms per cubic centimetre, and is largely influenced by the presence of occluded gas, being increased by annealing in an inert gas at low temperatures and diminished by annealing *in vacuo*. The electrical resistance of commercial cobalt is 231×10^{-7} to 103×10^{-7} ohms per cubic centimetre, and is greatly reduced by annealing *in vacuo*. The specific heat of pure cobalt between 0° and 890° C. is given by the formula:— $0.1058 + 0.0000457t + 0.0000000661t^2$. The paper is illustrated by eleven photomicrographs.

Long Reinforced Concrete Bridges. ANON. (*Sci. Amer. Supple.*, lxxix, No. 2041, 109.)—Reinforced concrete is so rapidly coming into general use that figures relating to bridges of this construction are of unusual interest. The Walnut Lane bridge has a span of 233 feet; at Grafton, New Zealand, there is a bridge with a span of 320 feet; over the Tiber, at Rome, 328 feet; at Largweiz, Switzerland, 330 feet; and the proposed bridge over Spuyten Duyvil Creek, New York, 703 feet.

THE IONIZING POTENTIAL OF AN X-RAY TUBE.*

BY

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THE following is a brief account of a research undertaken by the writer to obtain further information regarding the ionizing potential of an X-ray tube.

For a long time various German and American authorities have been asserting that the ionization potential of a Röntgen tube was higher than the running potential; or, in other words, that it takes a much higher voltage to break down the gap between the electrodes, so to speak, and start the ionizing currents flowing than it does to maintain this flow, once started. As to the real basis for this belief very little information can be found. It seems, in many respects, to be another case of "Newton said it is so, and so it must be."

To quote from several sources, we find that "Once the path is rendered conducting, the flow through the tube is accomplished more easily. The resistance of the tube falls off and the drop across the tube decreases. A current now flows through the tube on account of the diminished resistance, until finally the voltage has decreased so much that the flow stops" (Dessauer [1]). "The flow of current—after the breaking down of the tube—does not cease even if the voltage drops considerably below the break-down potential. If one excites a Röntgen tube with an alternating current, the flow of current does not start at the same instant that the potential passes through zero value, but delays in starting until the attainment of the break-down potential. The current starts as soon as this point is reached, and also continues after the voltage has fallen below it" (Fürstenau [2]). "Finally, the current falls again rather suddenly and apparently at the same time as the potential until the slowly-decreasing voltage of the transformer is no longer sufficient to pierce the tube vacuum. The value of this potential, however, is considerably less than that

* Communicated by Mr. H. Clyde Snook.

which was necessary for the original breaking down of the tube resistance. For the resistance of the tube vacuum always falls to a quite noticeable extent during the stream passage, in consequence of the ionizing action of the current itself" (Albers-Schönberg [3]). "In the case of the X-ray tube, as the break-down voltage is higher than the running voltage, it is doubtful what precisely either voltmeter or spark gap affords" (Kaye [4]). "In the ordinary tube (gas tube) the break-down voltage is much higher than the running voltage" (Coolidge [5]). "No focus tube has so far been found which will maintain a greater unfluctuating voltage than 100,000 volts, although many tubes need a greater voltage than this to get them to light up" (Cabot [6]). Many other similar statements can be found in articles and works of recent date, but the above are sufficient to point out the prevailing impression among those who have contributed some of the most valuable information in the field of röntgenology.

It was the opinion of the writer that an experimental investigation of the point would be interesting and might prove to be very much worth while. Although the work has not been carried to completion, it was thought desirable to publish the preliminary work, to which additions will be made in the near future.

In making a choice of methods, the sine wave form of the present type of high-tension machines generally used for tube excitation and the loop oscillograph seemed to lend themselves well to the work in view. A schematic diagram (Fig. 1), given herewith, shows the arrangement of the principal features of the apparatus.

The transformer and rectifying switch were of the Snook type, consisting of an inverted rotary directly connected to the mechanical switch. The oscillograph was of the General Electric type and contained three loops, carefully selected for sensitiveness and properly damped to just prevent overshooting at sudden changes of conditions. One of these loops (I_s) is placed directly in the secondary circuit between the high-tension terminals ($T\ T'$) and in series with the tube and milliammeter. Its function, as suggested, is to register the wave form of the secondary current. In series with the primary of the transformer is inserted a short piece of nichrome wire which serves as a shunt to the loop (I_p). This shunt and loop together constitute the recording device for

the primary current. A third loop (E_p) in series with a non-inductive resistance is placed directly across the primary winding alone. This indicates the curve form of the primary electromotive force and incidentally to a reduced scale (depending on the ratio of transformation) the potential across the secondary terminals at the same time.*

For purposes of calibration, a source of direct current may be applied through the control and primary of the transformer. This will produce a constant deflection in two of the loop systems (I_p and E_p), which can be shown directly on the film. By an auxiliary circuit of cells and resistance the third loop (I_s) may be similarly calibrated (see Figs. 1 and 7).

* That this is possible is apparent when we note that the reactance of the secondary circuit is practically negligible, there being only the self-induction and capacity of the tube, milliammeter, oscillograph loop, and straight connecting leads, with a ground connection between the tube and loop.

The ground connection is necessary for protection on account of insufficient insulation, and, in the opinion of the writer, is justifiable. Both Snook[7] and Duddell[8] used a ground in their work with the induction coil, and, although criticised by Wertheimer,[9] the latter's criticisms are not valid in the present instance. For:

1. The loops used have a free period of less than 1/5000 second, which would seem to be adequate when we consider that the speed of the rotary is only 30 revolutions per second. In the curves shown here the time taken for a half wave is 1/120 second.

2. The secondary potential is measured by an indirect method, which is not open to the objections raised in a direct method (viz., same current through the loop as through the main circuit).

3. The loops used are sufficiently sensitive for the currents involved.

4. To the writer's knowledge, no evidence has ever been given of errors introduced by making a point of zero potential in a closed circuit of this kind. At any rate, it is a question of doing this or something else perhaps equally objectionable.

Bown,[10] in a recent article on the wave form of currents in a Coolidge tube, adopted the scheme of inserting a small current transformer in the secondary circuit and in series with the tube. He claimed thereby an advantage of obtaining large-sized deflections for small-sized currents. Both Snook[11] and Salomonson,[12] by means of an oscillograph, have shown the oscillations which occur in the primary and secondary of a transformer or coil, and they explained them as functions of the capacity and self-induction of both circuits, together with the kind of a load on the secondary. The writer's experience with the oscillograph leads him to believe that the oscillations which follow the main impulses of the inductor in Bown's curves are probably due to the effects introduced by the use of the current transformer.

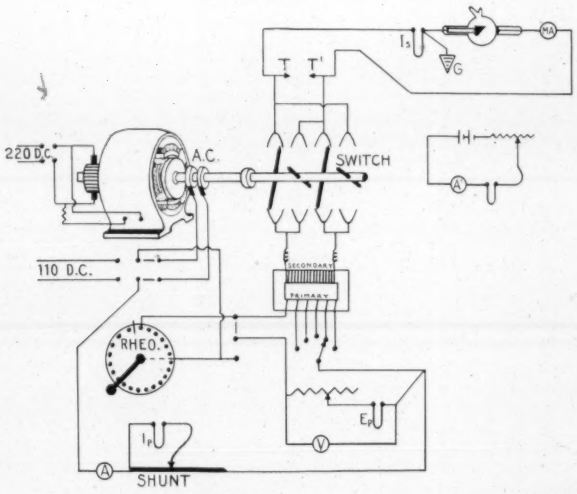
The tubes used were of standard commercial types, which may be divided into three classes:

1. The old type of gas tube, with the chemical regulator introducing a more or less complex gas.

2. The new hydrogen tube, with an osmosis regulator which admits only pure hydrogen.

3. The electron tube, which depends on a hot cathode to supply the electrons of the cathode stream.

FIG. 1.



Schematic diagram of apparatus.

The hydrogen tube has been used to a far greater extent in the preliminary work because of its great flexibility, which enables the operator to control the vacuum in either direction, up or down.

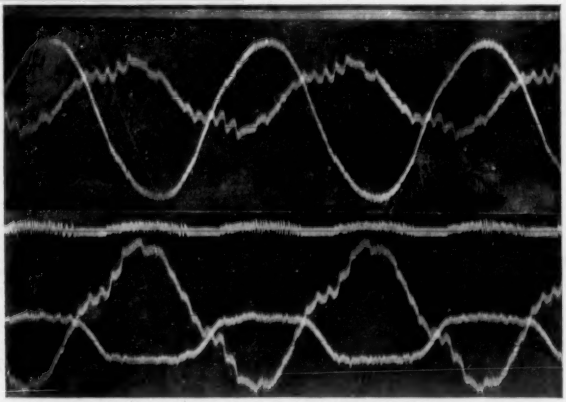
Oscillograms were taken as indicated, some of which are discussed herewith.

If the secondary of the machine is left open-circuited and only the corona effect allowed between the terminals, the milliammeter will read practically zero and the primary electromotive force will

be nearly sinusoidal in form. The primary current will be that necessary to produce the magnetization in the transformer iron, to charge the high-tension switch and secondary terminals electrostatically, and to furnish the current represented in the energy of the corona. This condition of affairs is shown in Fig. 2.

If we leave all the controls as above and insert an X-ray tube between the two terminals, the wave forms will be modified (see Fig. 3). The top curve is the current through the tube, a rectified sine wave in form. The current curve in the primary

FIGS. 2 AND 3.

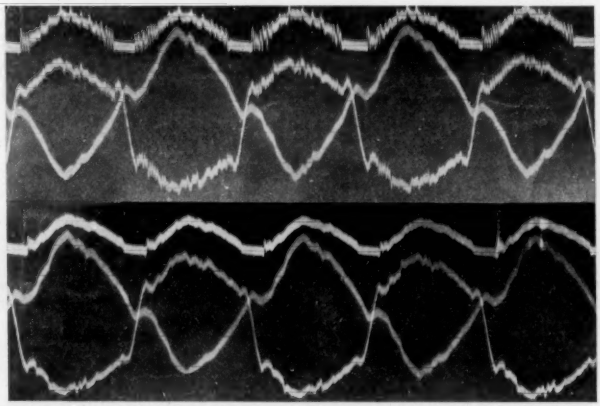


has changed its phase relation slightly, and the amplitude has been increased to correspond with the production of current in the secondary. The potential (either primary or secondary, as stated above) still starts from zero along the sine path, but as soon as the potential has risen to a value where the gas begins to ionize, it remains *practically constant* until the mechanical switch is opened. Question: *If, as is claimed by so many, the ionization potential is so very much greater than the running potential, why should there not be a high peak in this curve at the beginning of the half cycle?*

The conditions in Fig. 4 are similar to those in Fig. 3, except that the controls have been adjusted to allow more current to pass through the tube. The voltmeter reading in this case was 107 and the milliammeter reading was 32.

The small oscillations shown in the potential and secondary current curves are due to the air gaps at the ends of the revolving arms in the rectifying switch. To eliminate these and obtain smooth curves, small wire brushes were soldered on the ends of the arms. These made a rubbing contact with the metallic

FIGS. 4 AND 5.

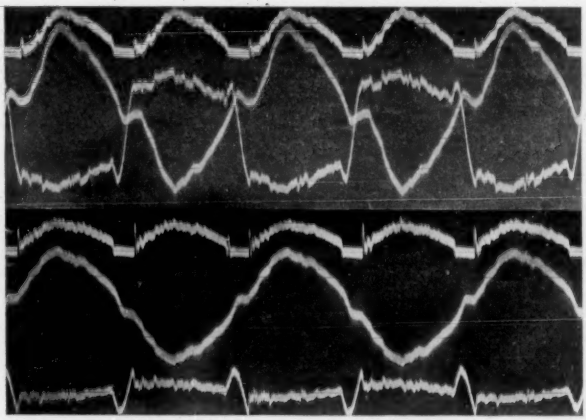


arcs of the switch and produced results shown in Fig. 5. Here the meter reading of the current through the tube was 40 milliampères. The integrated value of the volts drop across the tube was about 83,300 volts, with a maximum value about 20 per cent. greater. Both the current and potential curves are much smoother than in the preceding figures, but there are apparent differences in the separate half cycles and there are teeth at both the beginning and end of the flow of current. (The meaning of these teeth will be discussed at a later date.) However, even this condition of affairs was not stable, since the brushes were bent

back by the centrifugal force, and in some cases either cut or broken off by contact with the sharp edge of the metallic arcs.

The next step was to make the air gaps a minimum without necessarily making absolute contact at all times. With this arrangement an exposure is made (Fig. 6*a*) and the reading of the milliammeter very carefully noted. The oscillations are rather more prominent than in Fig. 5, but the wave forms were considered sufficiently good for first approximations. These curves portray what takes place in a hydrogen tube when backing up a

FIGS. 6A AND 6B.

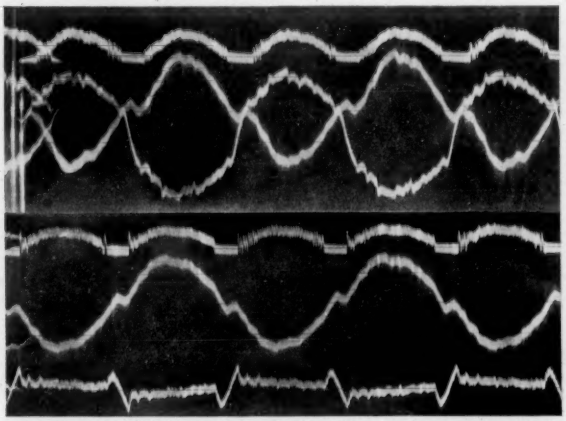


3½-inch parallel spark at 10 milliampères and carrying 36 milliampères at the instant of exposure. The upper curve is still the current passing through the tube. The ordinates of the potential curve, however, are not the potentials just sufficient to overcome the tube resistance, but include, in addition, the potential required to break down the little spark gaps in the mechanical switch.

Now, having noted with care the number of milliampères flowing in the secondary, the secondary terminals were short-circuited directly through the oscillograph loop and milliam-

meter without the tube. The rheostat in the primary circuit was then adjusted to permit the same current to flow through the loop (36 milliampères) that was flowing through the loop and tube, but without changing any of the other controls at the oscillograph. The potential curve (bottom of Fig. 6*b*) this time represents only the drop across the spark-gap resistance, and it is thus a question of subtracting these ordinates from the corresponding ones above to obtain data which will enable us to plot a curve representing the potential just sufficient to keep the gas of the tube

FIGS. 7 A AND 7 B.



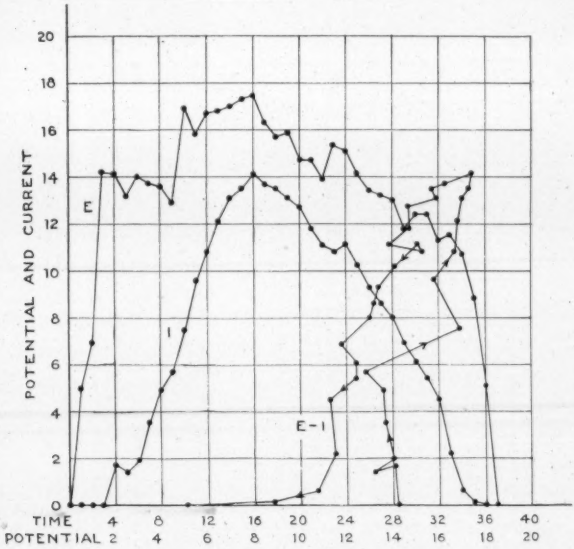
in an ionized condition. The current curves corresponding, although of slightly different shape, still have approximately the same integrated values as in Fig. 6*a*.

Figs. 7*a* and 7*b* are similar to Figs. 6*a* and 6*b*, except that a M. & W. tube (representative of the ordinary gas tube with chemical regulator) was used. This tube was backing up a 3¼-inch parallel spark at 5 milliampères and carried a current of 28 milliampères at the instant of exposure.

Fig. 8 contains the plots indicated in Fig. 6. Similarly, Fig. 9

shows the plotted curves for conditions indicated in Fig. 7. Also in Fig. 10 plots have been made for another hydrogen tube. The corresponding oscillograms are not reproduced, but the tube backed up a parallel spark of 3½ inches at 6 milliampères and carried 18 milliampères at the instant of exposure.

FIG. 8.



Hydrogen tube.

Curve E. Plotted potential against time.
Curve I. Plotted current against time.
Curve E–I. Plotted current against potential.
Scales: 10 divisions = 62 volts primary or 47,400 volts secondary.
10 divisions = 61 milliampères.
37 divisions = half cycle or $\frac{1}{120}$ second.
Maximum potential = 82,500 volts.
Maximum current = 86 milliampères.

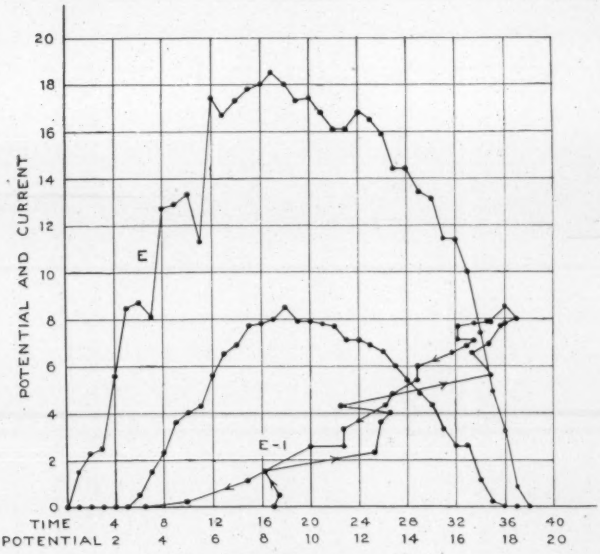
A glance at these curves and plots offers some interesting suggestions.

1. The oscillograms point to the X-ray tube as a constant potential device which tends to maintain a constant drop across it.

2. The approach of the potential-current plots of Figs. 8, 9,

and 10 to a half loop of the ordinary magnetic hysteresis cycle is notable, and is indicative of something different than a straight line law, like Ohm's law, in the tube circuit. In fact, it would seem that the law connecting the current and potential in a circuit of this kind is that of the ordinary saturation curve.

FIG. 9.



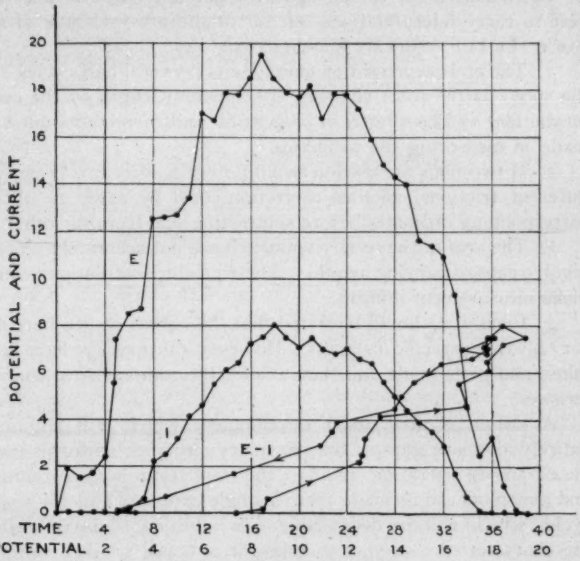
M. and W. tube.
Curve E. Plotted potential against time.
Curve I. Plotted current against time.
Curve E–I. Plotted current against potential.
Scales: 10 divisions = 78 volts primary or 43,200 volts secondary.
10 divisions = 61 milliampères.
38 divisions = half cycle or $\frac{1}{120}$ second.
Maximum potential = 80,000 volts.
Maximum current = 52 milliampères.

3. The area enclosed in this loop is a measure of the energy of ionization. We may call the curve, if we like, an ionization hysteresis loop.

4. The energy which goes into ionization in the hydrogen tube is apparently a greater percentage of the total energy supplied

than in the M. & W. tube. Roughly speaking, it is estimated that about 40 per cent. of the energy supplied to the hydrogen tube goes into ionization, as against about 20 per cent. in the case of the M. & W. tube. This may account for the fact that more

FIG. 10.



Hydrogen tube.

Curve E. Plotted potential against time.
Curve I. Plotted current against time.
Curve E–I. Plotted current against potential.
Scales: 10 divisions = 89 volts primary or 40,800 volts secondary.
10 divisions = 61 milliamperes.
39 divisions = half cycle or $\frac{1}{120}$ second.
Maximum potential = 79,100 volts.
Maximum current = 49 milliamperes.

heat appears during operation in the latter case than in the former.

5. The arrows show the direction in which the loops are traced and indicate that there is an ionization potential distinct from the running potential. However, it is nothing of the order that is generally supposed. In the plot of Fig. 9 the descending and

ascending parts of the loop actually cross each other. This may be due to errors in measurement or possibly to the complexity of the gas in the M. & W. tube. In any event, the values of the potential needed to maintain any particular current are not widely divergent for the two sides of the loop.

In conclusion, it should again be pointed out that it is not best to carry interpretations too far at the present stage of the work. Certain errors are known to exist.

1. The plots represent an average over several half cycles. If the speed of the rotor changes, the apparent length of the cycle on the film will be altered in proportion and corrections must be made in measuring the ordinates.

2. If two films are used in two different holders involving two different frictions, another correction must be made to obtain corresponding ordinates before subtracting one from the other.

3. The arcs in the rectifying switch are not accurately set and involve gaps of varying lengths. These produce oscillations which make measurement difficult.

4. Finally, it should be stated that the curves shown here are for only three specific instances. However, other curves have been taken and plots made and they exhibit the same general characteristics.

A switch is now under development which will eliminate entirely all spark gaps in the secondary circuit. With this completed and in operation, most of the oscillations will be omitted and new plots can be made from a single exposure and for single cycles which will be dependable. In addition to investigating the characteristics of various tubes, it is hoped to also continue the investigation to determine the properties of spark gaps in general. Several other problems have been suggested to the writer during the course of the work and these, together with further results, will be reported at some future time.

This work is the outcome of research started last year in a slightly different field at the University of Pennsylvania. The work has been carried forward under the direction of Mr. H. Clyde Snook, to whom I am greatly indebted for many valuable suggestions and a large part of the apparatus used.

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Randal Morgan Laboratory of Physics,
University of Pennsylvania,
Philadelphia.

Alite the Chief Constituent of Portland Cement Clinker. E. JÄNECKE. (*Z. Anorg. Chem.*, lxxxix, 355.)—Alite, the mixture of composition, $8CaO$, Al_2O_3, $2SiO_2$, was found to possess a maximum melting-point, 1385° C., in the ternary system, $CaO - Al_2O_3 - SiO_2$, and it therefore probably represents a definite compound. It has a specific gravity 3.035, refractive index 1.63, and hardness 7 on Moh's scale. The substance known as alite, which crystallizes from cement clinker, exhibits all the properties of the above compound, and it is maintained, mainly on optical grounds, that the substances are identical.

Sugar Beet in Canada. F. T. SHUTT. (*Report of Dep. of Agric., Canada*, 1913, 242.)—Very satisfactory results have been obtained showing that sugar beets may be grown in widely distant parts of Canada. The highest sugar content, 17.86 per cent., was reached at Lethbridge, Alberta, and the lowest, 13.40 per cent., at Brandon, Manitoba, and at three of the experimental farms it averaged 17 per cent., the purity of the juice being over 90°.

Wireless Telegraphy. (*British Patent 27,480 of 1913.*)—A method of eliminating atmospherics, due to Marconi's Wireless Telegraph Company, Ltd., and H. J. Round, is described. The atmospherics aimed at are those which cannot ordinarily be tuned out. A receiving circuit slightly out of tune with the signal waves is employed, so that the induced free and forced oscillations are of suitable relative frequency to produce beats. These beats are rectified, and the detecting circuit is tuned to their frequency.

Recovery of Actinium and Ionium from the Olary Ores. S. RADCLIFFE. (*Chem. News*, cxi, 59.)—*Actinium.*—Almost the whole of this constituent appears to be precipitated with the mixed crude sulphates obtained in the course of extracting the radium. The mixture, containing about three per cent. of rare earths in addition to the constituents enumerated, is fused in an iron crucible with excess of sodium hydroxide containing some sodium carbonate, the melt extracted repeatedly with hot water, the insoluble residue digested with excess of sodium carbonate under a steam pressure of ninety pounds, the carbonate residue washed, treated with dilute hydrochloric acid, the solution evaporated to dryness, the residue treated with water, the silica filtered off, and the solution saturated with hydrochloric acid gas (to precipitate the radium and barium) and filtered. The filtrate, containing the actiniferous rare earths, is evaporated to dryness and the residue further treated to separate actinium. *Ionium* appears to be chemically inseparable from thorium, so that by extracting and purifying the latter by any of the well-known methods an active ionium product is obtained. The activity of this product depends on the ratio between the uranium and thorium present in the ore, this ratio being about 100 : 1 in the case of the Olary ore.

German Iron and Steel Production in 1914. ANON. (*Engineering*, Feb. 12, 1915.)—The Union of German Iron and Steel Industries states that the production of pig iron within the German Customs Union for December, 1914, amounted to 853,881 tons, against 1,611,250 tons for December, 1913, while there was an improvement as compared with November, 1914, for which the figure was 788,956 tons. The production of pig iron per day, since the war began, averaged: August, 18,925 tons; September, 19,336; October, 23,543; November, 26,299; December, 27,545 tons. The production for December comprised: Foundry pig, 148,881 tons; Bessemer pig, 8778; Thomas pig, 542,808; steel, etc., 128,347; puddle, 25,097 tons. The aggregate production of the different brands for the last two years was:

	1914	1913
Foundry pig	2,494,527	3,657,326
Bessemer pig	237,988	368,840
Thomas pig	9,289,989	12,193,336
Steel, etc.	1,996,786	2,599,887
Puddle	370,257	489,783
	14,389,547	19,309,172

The reduction in the production was most marked in Lorraine, Luxemburg, Rhineland, and Westphalia, while less pronounced in Silesia.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

THE EMERGENT STEM CORRECTION FOR THERMOMETERS IN CREOSOTE OIL DISTILLATION FLASKS.

THERMOMETERS used in distillation flasks are subject to error if a portion of the thermometer stem, containing the mercury column, is emergent from the flask and is at a temperature different from that of the bulb.

This emergent stem correction error is discussed with particular reference to creosote oil distillation. Emergent stem corrections were determined, applicable to a particular type of thermometer when used in four types of distillation flasks.

The average correction found for the ordinary side neck distillation flask at 200° C. was 4.5°; at 250°, 6.0°; at 300°, 10.5°; and at 350°, 15.5°, with differences of as much as a degree between the same readings on different runs, making it evident that the average corrections could not be relied upon to better than a degree. For the same temperature, using the same thermometer in different flasks, the greatest difference in the stem corrections found was 2° C.

Reasons for variations in emergent stem corrections for different runs on the same flask are discussed. The greatest errors are caused by the use of unsuitable thermometers, and variations in the rate of rise. The most desirable thermometer for distillation flasks seems to be a continuous scale graduated stem type of mercurial thermometer having a length of about 40 cm.

The effect of radiation and condensed vapor on temperature measurement is discussed.

The magnitude of the disagreement in distillation results, when in one case allowance is made for stem correction and in another case it is not, is shown by example.

A method was suggested by which the total correction (including scale correction and emergent stem correction) to a thermometer used in distillation flasks can be determined at two points by reading the thermometer first in the vapor of boiling naphthalene

* Communicated by the Bureau.

(temperature 218° C.), and in the vapor of boiling anthracene (temperature 340° C.). Interpolations for the corrections between these two points can then be made. This method was investigated and found to be reliable to one or two degrees.

AN AIR-ANALYZER FOR DETERMINING THE FINENESS OF PORTLAND CEMENT.

By J. C. Pearson and W. H. Sligh.

[ABSTRACT.]

THE increasing demand for more finely ground Portland cement has necessitated a further investigation of the value of fineness, particularly from an economic standpoint. An adequate investigation of this kind can be undertaken only when some further method of separating the "fines" from the No. 200 sieve is available, and therefore a number of attempts have been made in recent years to develop an elutriator for this purpose.

Two years' experience has shown that a satisfactory elutriator must meet the following fundamental requirements: (1) The apparatus should ensure, so far as possible, a constant velocity and uniform stream lines in the fluid as it passes through the separating chamber. (2) The fluid should not be appreciably retarded by the material under examination, or by constrictions or obstructions in that part of the apparatus beyond the separating chamber, unless the amount of such retardation can be determined by pressure gauges or compensated by special devices. (3) All particles of the material should be completely and continuously exposed to the action of the fluid, so that any which are capable of passing through the separating chamber may have every opportunity to do so. (4) The separating chamber should have no places of lodgement for material. (5) The apparatus should be capable of separating fair-sized samples, preferably 25 grammes or more. If these requirements are embodied in the construction of a given elutriator, its shape, dimensions, and working conditions are of secondary importance, and can readily be adapted to give the desired separations.

A review of earlier types of elutriators used or proposed for cement testing shows that some are faulty in design or unnecessarily complicated, while others are probably capable of making

good separations. Only one serious attempt appears to have been made to identify the separations in terms independent of the particular apparatus employed, and this not in a manner to enable comparisons to be made with results obtained by others.

After a series of preliminary experiments, an air-analyzer has been developed at the Bureau of Standards which seems to meet the fundamental requirements and appears to give reliable separations of cement and certain other materials. The distinguishing features of the apparatus are: the introduction of an unretarded air stream into a conical-shaped bulb in such manner that the sample under examination is completely and continuously exposed to the action of the air; a separating chamber of considerable height which permits no lodgement of either fine or coarse particles; a tapping device to minimize the adherence of fine dust to any part of the apparatus; and a collector which catches and holds all material passing through the separating chamber.

The main objection to elutriation methods appears to have been the lack of standardization of apparatus heretofore used. An endeavor has therefore been made to define the separations obtained by the air-analyzer in terms of the limiting sizes of particles in the different fractions. These limiting sizes, designated as the "sizes of separation," may be interpreted in different ways, depending upon the methods of measurement. Several methods of measurement have been studied, and a system has been provisionally adopted which appears to be the simplest and most direct, although not giving directly the "true diameters" of the particles under examination. The relations between the "apparent" and "true" sizes of particles have been expressed by means of reduction factors, which enable one to convert from one system to another.

A preliminary study has been made of the effects of abrasion, specific gravity, atmospheric conditions, and other factors on the separations, but much more work remains to be done before the limitations of the analyzer can be established with certainty. It seems probable that under normal operating conditions the nominal sizes of separation of the analyzer determined by calibrations with normal cements will be within about five per cent. of the actual sizes. This gives rise to a possible error of about 1.5 per cent. in estimating the quantity of any desired fraction from

the mechanical analysis curve. As the error in determining the percentage of any given fraction by actual separation in the analyzer is probably not greater than 0.5 per cent., it may be assumed that routine analyses, without special calibrations, will enable one to determine the quantity of particles below a given size in any normal cement within two per cent. If greater accuracy is desired in special comparisons or in other important cases, calibrations can be made on the material under examination without excessive labor.

Further lines of investigation have been suggested, particularly in modifying the apparatus to yield still finer subdivisions. In making this change it is proposed to adapt the apparatus, if possible, to separations of organic and other powders which are not capable of withstanding the abrasive action produced by the air blast in the present type of bulb and nozzles.

The analyzer has been developed with the particular purpose in view of determining the granulometric composition of very finely ground and air-separated cements to be used in a further investigation of the value of fine grinding which is now under way. It is also adapted in its present form to comparisons of the products of different finishing mills, and to the separation and grading of abrasives and other hard-grained materials. In view of the considerable variety of finely-divided materials already tested with the analyzer, the apparatus promises to have a much broader field of usefulness than that for which it was originally designed.

THE CALCULATION OF THE MAXIMUM FORCE BETWEEN TWO PARALLEL, COAXIAL, CIRCULAR CURRENTS.

By Frederick W. Grover.

THE force of attraction or repulsion between two currents flowing in parallel, coaxial, circular paths of unequal radii increases as the distance between their planes is increased, until a maximum value of the force is reached, and then, as the distance is indefinitely increased, decreases toward zero as a limit.

It was shown by Maxwell that the distance for which the force is a maximum bears a ratio to either of the radii, which is a function of the *ratio of the radii alone*, and depends in no way on their

absolute values. Further, the maximum value of the force, with unit current in each circuit, is also a function of the radii alone.

These facts have been utilized in the current balance, first used by Lord Rayleigh, in which is measured the force between two parallel, circular, coaxial coils, one fixed and the other attached to one end of the beam of a balance, the distance between the planes of the coils having been adjusted until the force exerted between the currents in the coils is a maximum. From the observed weights, which must be added to the other arm of the balance to restore equilibrium, the value of the current flowing through the two coils in series may be calculated, provided the ratio of the radii is known. The latter may be determined experimentally by an electrical method, without measuring the individual radii, and with an accuracy not attainable from direct measurements of the dimensions of the coils.

The calculation of the constant of the balance is based on the theory for two circular filaments to which the coils may be regarded as equivalent. The corrections necessary to be taken into account because of the finite cross-section of the coils have been derived by Rayleigh, Lyle, and others, and reference may be made to the paper on the "Determination of the International Ampère in Absolute Measure," by Rosa, Dorsey, and Miller, for a treatment of this question and for other details concerning the theory and methods of manipulation of the balance.

The force between two parallel, circular, coaxial currents of given radii, situated with any desired distance between their planes, may be calculated by the formula of Maxwell in elliptical integrals, or the formulas of Nagaoka which involve q series.

Previously, the value of the maximum value possible of the force between any two such circular currents, of given radii, has been obtained by calculating the force directly (by means of the formulas just mentioned) for a number of chosen distances of the coils in the neighborhood of the critical distance, which was supposed to have been approximately determined beforehand. The final value of the maximum force was determined by interpolation from this series of calculated values. This process is indirect and laborious.

In the present paper is derived a formula for calculating the value of the critical distance from the assumed ratio of the radii. By substituting the distance thus found in one of the above general

formulas for the force, the maximum value of the force may at once be determined. In some cases the maximum force may be calculated directly from a formula given here in which this substitution has been made once for all.

The formula for the critical distance is, unfortunately, not simple enough to allow of the direct calculation of the critical distance from the given ratio of the radii. It is, however, not difficult to obtain the desired value with great accuracy by a method of successive approximation, provided a first approximation is at hand.

The latter part of the paper is devoted to the development of methods for facilitating this process. The formulas derived are fully illustrated by numerical examples, and tables are given of the critical distance and the value of the maximum force for such values of the ratio of the radii as are likely to occur in practice. It is further shown how the constants for coils, whose dimensions differ slightly from one of the exact ratios given in the tables, may be derived from the latter values with little trouble and labor.

To test the new formulas the complete calculations of the constants of the coils of the Bureau of Standards current balance have been carried through, and the results were found to be in agreement with the values obtained by the interpolation method within less than a part in a million.

THE EFFECTIVE RESISTANCE AND INDUCTANCE OF IRON AND BIMETALLIC WIRES.

By John M. Miller.

WHEN a current of electricity flows through an iron wire the lines of magnetic force and the resulting magnetization of the iron are circular. From measurements of the self-inductance of the wire with direct current an exact permeability curve for circular magnetization can be obtained. As ordinarily measured, the permeability for axial magnetization is obtained. A comparison of the two kinds of magnetization shows that for some wires the permeability curves are similar, but for others the circular permeability may be considerably less than the axial. The differ-

ences are due probably to lack of homogeneity or isotropy of the iron caused by drawing and by heat treatment.

A method based upon Anderson's modification of the Maxwell bridge for measuring inductances is used to measure the effective resistance and inductance of six samples of iron telegraph and telephone wires and three samples of copper-clad steel, bimetallic wires. The measurements are made at frequencies up to 3000 cycles per second and with currents up to 10 amperes. The results are given by tables and curves. The so-called steel telephone wires are considerably poorer conductors at low frequencies and low current strengths than the grade called "Extra Best," but at higher frequencies and current strength the steel wires may be better conductors.

At the higher frequencies the resistance and inductance of the copper-clad wires become practically independent of the current flowing through the wire.

From considerations of bimetallic wires as two circuits in parallel, formulas are obtained which permit the computation of effective resistance and inductance of the wires. The core is treated as one circuit, the shell as another, and the self-inductance of each is computed as well as the mutual inductance of one on the other. Assuming no skin effect in the shell and introducing the effective resistance and inductance of the core for a given frequency, the resistance and inductance of the whole wire can be computed for that frequency from the expressions for the equivalent resistance and inductance of two circuits in parallel. The measured values of the copper-clad wire for low-current strengths are compared with the computed values, and the agreement is very satisfactory. The formulas are also used in computing wire tables for copper-clad steel wire. Values of effective resistance and inductance are tabulated for the even sizes from No. 0 to No. 12 A.W.G. for conductivities of 30, 40, and 50 per cent. of hard-drawn copper and for frequencies up to 1000 or 3000 cycles per second.

The Gyro-compass in the Navy. ANON. (*Sci. Amer.*, cxii, No. 7, 153.)—Gyro-compasses have now been installed on twenty battleships, one armored cruiser, and fifteen submarines of the United States Navy, and it has recently been decided to install master compasses in duplicate on all battleships of the *Delaware* class and later. Special attention is being paid to the instructions of officers and men in the care and use of these compasses by sending them for a month's instruction at the New York Navy Yard or at the works where the compasses are made. The Bureau of Navigation also maintains with the Atlantic fleet two chief gunners who have been specially trained as gyro-compass experts, their duty being to inspect and adjust the compasses and give instruction in their use.

India Rubber Production in 1914. S. FIGGIS AND CO. (*India Rubber J.*, xlix, 77.)—In 1914, 14,800 tons of plantation rubber were exported from Ceylon and India and 49,700 tons from Malaya, etc., as compared with 11,830 tons and 36,200 tons respectively in 1913; the 1914 figures do not include some direct Dutch shipments. The supply from Brazil, including Amazonas, Bolivia, Peru, etc., was 37,000 tons in 1914, against 39,000 tons in 1913. The total production of raw rubber in 1914 is estimated at 115,500 tons. Practically no guayule was made and less reclaimed rubber was used. Exports in 1914 from West Africa amounted to 8500 tons, from Loanda 450 tons, and from Congo, French Congo, and Sudan 3900 tons, the corresponding figures for 1913 being 10,000, 400, and 4400 tons respectively. England imported 2650 tons and France 1700 tons from West Africa in 1914.

Explosion of an Electric Transformer. ANON. (*Sci. Amer. Supple.*, lxxix, No. 2040, 89.)—The explosion of a large electric transformer in South Africa appears to have developed a new fact that was not known before. In taking down the transformer for repairs the workmen proceeded to drain the expansion tank located above the transformer of the oil it contained, and before doing so a man held a lighted match over a slight hole in the tank, when a severe explosion occurred that either killed or severely burned every man present, besides setting fire to everything inflammable in the transformer chamber. As the oil in the tank was not above 34° C., and its flash-point was 140° C., the gas that caused the explosion could not have been oil-vapor, and experiments were instituted, using extra high tension discharges under transformer oil. Samples of the resulting gases were collected, which on analysis proved to contain at least 62 per cent. hydrogen. It is evident, from this experience, that great care should be exercised not to allow a naked light near transformer oil tanks or oil switches until they have been thoroughly ventilated.

THE FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, May 19, 1915.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 19, 1915.

PRESIDENT WALTON CLARK *in the Chair.*

Additions to membership, 3.

The Chairman recognized Dr. Harry F. Keller, who introduced Chevalier van Rappard, of Washington, D. C., and Mr. Thomas A. Edison, of Orange, N. J., to whom presentations of The Franklin Medal were made, that to Chevalier van Rappard being on behalf of the Royal Netherlands Government for Prof. Heike Kamerlingh Onnes, of Leiden, Holland.

The Chairman then recognized Dr. George A. Hoadley, who introduced Mr. Samuel Insull, of Chicago, Ill., founder of The Franklin Medal Fund, to whom was presented a sculptor's model in bronze of The Franklin Medal.

After the presentations, Mr. Insull delivered an address, entitled "Electricity and Modern Industrial Growth," which was illustrated by lantern slides.

Adjourned.

R. B. OWENS,
Secretary.

(A full account of the meeting will appear in the next issue.)

CORRESPONDENCE.

LEIDEN, 27 April, 1915.

DR. R. B. OWENS, *Secretary of*
The Franklin Institute of the State of Pennsylvania, Philadelphia.

SIR:

I beg to express my sincere gratitude for the honour The Franklin Institute has bestowed upon me by awarding me The Franklin Medal.

The appreciation of my labors in low-temperature research by The Franklin Institute is a great satisfaction for me.

I regret that it is not possible for me to come to the meeting of 19 May next, and I beg to thank you for inviting Chevalier W. F. L. C. van Rappard, my Government's Minister at Washington, to have the kindness to receive the medal and certificate on behalf of my Government for me.

I am respectfully,

[Signed] H. KAMERLINGH ONNES.

FROM THE LABORATORY
OF
THOMAS A. EDISON,

ORANGE, N. J., April 14, 1915.

MR. R. B. OWENS, *The Franklin Institute*
of the State of Pennsylvania, Philadelphia, Pa.

DEAR MR. OWENS:

I received both your official and personal letters in regard to the action of Institute in awarding me The Franklin Medal, and was greatly surprised, as this was the first intimation I had of any such thing.

I shall not attempt to say how deeply I am gratified on this mark of distinction, because I am unable to do so adequately. Let me say, however, that I am deeply appreciative of the honor thus conferred upon me, and I thank you for your personal congratulations and kind expression of sentiment in regard to myself.

. . . . . .

With kind regards, I remain,

Sincerely yours,

[Signed] THOMAS A. EDISON.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, May 5, 1915.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 5, 1915.

MR. G. H. CLAMER *in the Chair.*

The following reports were presented for final action:

No. 2613.—Anderson Gear Rolling Machines. John Scott Legacy Medal and Premium recommendation to Harold N. Anderson, of Cleveland, Ohio, adopted.

No. 2633.—Owens Bottle Making Machine. Elliott Cresson Medal to Michael J. Owens, of Toledo, Ohio, adopted.

On the recommendation of the Subcommittee on Literature, the following awards were made for papers in the JOURNAL, 1914:

No. 2645.—The Howard N. Potts Medal to Dr. William J. Humphreys, of Washington, D. C., for his paper entitled "The Thunderstorm and Its Phenomena," described by the subcommittee as an original, comprehensive, and authoritative presentation of the phenomena of the thunderstorm.

No. 2646.—The Edward Longstreth Medal of Merit to Dr. Herbert E. Ives, of Philadelphia, Pa., for his paper entitled "Artificial Daylight," described by the subcommittee as an account of important original investigations in the field of illumination.

No. 2647.—The Edward Longstreth Medal of Merit to Dr. M. von Recklinghausen, of New York, N. Y., for his paper entitled "The Ultra-violet Rays and their Application for the Sterilization of Water," described by the subcommittee as a lucid description of a novel and practical application of ultra-violet rays.

No. 2648.—The Edward Longstreth Medal of Merit to Mr. C. C. Tutwiler, of Philadelphia, Pa., for his paper entitled "The Recovery of Gas Works By-products," described by the subcommittee as a comprehensive account of the most recent developments in this field.

No. 2649.—The Edward Longstreth Medal of Merit to Mr. C. D. Young, of Altoona, Pa., for his paper entitled "Locomotive Superheaters and their Performance," described by the subcommittee as a thoroughgoing review of the development of the locomotive superheater, together with an account of a highly valuable research.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, May 12, 1915.*)

RESIDENT.

MR. WILLIAM H. HARDING, 1722 Land Title Building, Philadelphia, Pa.

MR. WILLIAM STANTON TWINING, 119 Harvey Street, Germantown, Philadelphia, Pa.

ASSOCIATE.

MR. HENRY RAWLE PEMBERTON, 1008 Clinton Street, Philadelphia, Pa.

CHANGES OF ADDRESS.

MR. FRANK M. ASHMEAD, 445 Ashland Avenue, Buffalo, N. Y.

MR. WALTER F. BALLINGER, northwest corner Seventeenth and Arch Streets, Philadelphia, Pa.

MR. EDWARD L. COSTER, Room 1440, 25 Broad Street, New York, N. Y.

MR. E. L. GIBBS, 602 King Street, Jacksonville, Fla.

MR. D. W. LUM, 1024 Munsey Building, Washington, D. C.

MR. EMILE G. PERROTT, northwest corner Seventeenth and Arch Streets, Philadelphia, Pa.

MR. ROBERT S. REDFIELD, Barnstable, Mass.

MR. ALBERT R. SHIPLEY, Thomaston, Conn.

MR. ORIN C. STOUT, 509 Hartman Building, Columbus, Ohio.

MR. ELLIS D. WILLIAMS, Box 274, Jenkintown, Pa.

MR. HERBERT W. YORK, 120 Broadway, New York, N. Y.

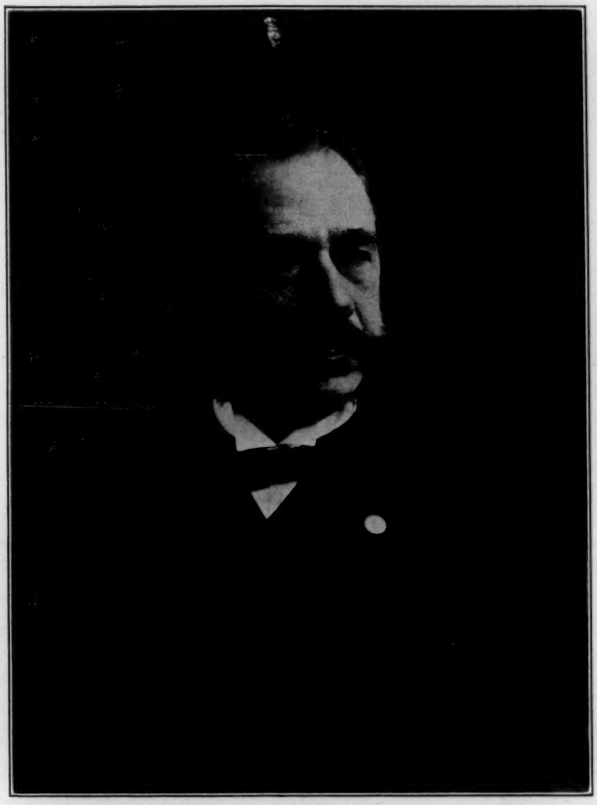
NECROLOGY.

John Birkinbine, ex-president of The Franklin Institute, a consulting engineer of international reputation, a pioneer in mining, metallurgical and blast-furnace construction, ended a long and eminently useful life at his home in Cynwyd, a suburb of Philadelphia, on Friday, May 14, 1915. He was born in Reading, Pa., November 16, 1844, the eldest son of H. P. M. Birkinbine, whose widely-recognized accomplishments in the field of hydraulic engineering established a name which the son, through a lifetime of successful effort, carried forward into the foremost rank of the engineering profession, and which his sons, in turn, are maintaining with honor in their generation.

John Birkinbine was educated in the public schools of his native city and in the Friends High School in Philadelphia, the Hill School at Pottstown, and the Polytechnic College of Philadelphia. His studies were interrupted in 1863–4 by his twice enlisting for scout duty in the Union Army, in which capacity he participated in the Gettysburg battles and campaign. In later years he was offered honorary degrees by two colleges, but modestly declined these on the ground that, having been unable to graduate from his own Alma Mater, he was not warranted in accepting them.

Following his army experience, young Birkinbine devoted two years to practical work in a machine shop and then took part in the firm of Weimer & Birkinbine, which operated the Weimer Machine Works at Lebanon, Pa. Thereafter he became associated with his father and had charge of much of the field work and construction which his father had in hand. Collaborating with him in the design and execution of various public water works, the utilization of water powers, and other similar undertakings, and clarifying his experiences by constant study, he soon attained a position of prominence as an expert consultant in important undertakings of this kind. Gradually his work became extended in the direction of mining, metallurgical and blast-furnace construction. As manager for the South Mountain Mining and Iron Company he carried through a series of experiments with various fuels for melting iron ore in continuous furnace operation. The carefully-recorded results which he obtained were widely published and are included in text-books as the most authentic data on the subject.

Mr. Birkinbine was called to nearly every State in the Union, to Canada and to Mexico, to make examinations and reports on the construction or improvement of iron ore mines, blast furnaces, iron works, water supplies, hydraulic development, irrigation projects, etc., his services in these directions having been requisitioned on a number of occasions by European corporations. Among his many expeditions of this nature, several were to Mexico, beginning with a journey to the Cerro de Mercado at Durango, before any railroad had been built in that region, there to make a critical examination and report on the "Iron Mountain." Later visits, covering other localities in Mexico and dealing with other engineering problems, familiarized him with the major part of the iron industry in that country. The enlargement, modernization, and improvement of much of the iron and steel industry of Mexico upon which he reported, after investigations made for various in-



JOHN BIRKINBINE
1844—1915

OBERLIN
COLLEGE
LIBRARY.

terests in Europe and America, await only the end of the present political disturbances in our neighboring republic.

Mr. Birkinbine was probably the first to suggest an iron industry at the head of the Great Lakes, using coke made from Pennsylvania coal; his report on the subject became an important factor in determining the establishment of the iron industry at the head of Lake Superior, and the blast furnace at West Duluth, Minn., was built on his plans and under his supervision. For some years he was consulting engineer for the Philadelphia and Reading Coal and Iron Company, and held a similar position with Mr. Thomas A. Edison during the early course of the experiments carried on by the latter on magnetic concentration of iron ore, with Witherbee, Sherman & Company in beneficiation tests, and with the Colorado Fuel and Iron Company in the enlargement and improvement of its works and the construction of an augmented water supply system. He acted on various occasions as expert for important financial interests, for a number of the greatest industrial corporations and for several of the large railroad companies in this country. His reports and recommendations are characterized by their clearly-stated conclusions, and his reputation for conservatism and fairness led to his being called upon for appraisements, adjustments, and arbitrations, in some of which he was accepted by mutual consent as the representative of both parties. To maintain his position of independence in this regard he declined all offers of contingent fees and refrained from patenting any of the numerous improvements which he originated.

Throughout his career Mr. Birkinbine made a specialty of hydraulic engineering, acting as engineer on water supplies for various municipalities. He not only witnessed but actively participated in the extensive application of water power for electrical energy which has marked these recent years. In 1888 he prepared a comprehensive report on the utilization of the great water power of the St. Louis River in Minnesota, taking a view of a 15-mile transmission, though no water-wheel manufacturer at that time would guarantee turbines for heads above thirty-five feet. Since then he has been associated with or reported on many hydraulic developments in various States of the Union and in Mexico, dealing with high heads or large volumes of water which until lately were regarded as impracticable.

The general interests of the engineering profession and the advancement of the sciences and arts in general evoked Mr. Birkinbine's active coöperation. Besides serving through the ten years from 1897 to 1907 as president of The Franklin Institute and through the rest of his years as member of its Board of Managers, he early participated in the activities of various other scientific societies. He took a leading part in organizing the Pennsylvania Forestry Association in 1886, and was its president for twenty-three years, during which period the association procured the establishment of a State Forestry Commission, latterly made a State department, and the enactment of various laws in furtherance of the forestry movement. The Bulletin of the Association, *Forest Leaves*, was edited by him from its inception to the date of his death. He was chairman of the Water Supply Commission of Pennsylvania from the time of its organization in 1905, devoting to its duties a large portion of his valuable time for a merely nominal recompense. For two-

score years he continued prominent in the American Institute of Mining Engineers, having been manager, vice-president, and president, being reëlected to this latter office to the limit set by the constitution, and he contributed largely to its proceedings and to other technical periodicals.

He was active in the formation and served as secretary of the United States Association of Charcoal Iron Workers, and for nine years edited its journal. For many years he was special agent for the United States Geological Survey, preparing the reports on iron ores for the eleventh and twelfth censuses, that on manganese ores for the twelfth census, and latterly additional data and studies for the Survey. He was appointed by the Secretary of the Interior expert metallurgical engineer for the Bureau of Mines, and received special marks of approval from the Survey and from several foreign scientific societies. He was a member of a number of international congresses, chief engineer, vice-president, and chairman of the Committee of Awards of the National Export Exposition, served on juries of award at the Centennial, Columbian, Pan-American, and Cotton States Expositions, and was named for similar duties at others. He was a member of the American Society of Mechanical Engineers, the Engineers' Club of New York, the American Society for Testing Materials, The Engineers' Club of Philadelphia (president in 1893), The Manufacturers' Club of Philadelphia, The Pennsylvania Foundrymen's Association, and an honorary member of the Canadian Mining Institute. He was also connected with the George G. Meade Post, No. 1, G. A. R., of Philadelphia. He became a member of The Franklin Institute in 1865.

Mr. Birkinbine constantly maintained a friendly interest in his fellow-members of the profession, and held to the thought that engineers were coöperators and not competitors. He continued his personal interest in all his associates and was ever ready to help young men by advice.

As a citizen he was always active in promoting the public good. He served on the Civil Service and other commissions, besides rendering professional services for the city of Philadelphia. His neighborly activities were maintained up to the end of his life. His last days were happily spent in the circle of his family, for as a devoted husband and father he fulfilled with a deep religious consciousness what he considered his greatest pleasure and the noblest of all his duties, those to his family and his home.

LOUIS EDWARD LEVY.

Charles Martin Hall was born at Thompson, Ohio, on December 6, 1863. He was graduated from Oberlin College in 1885 with the degree of Bachelor of Arts, and received his degree of Master of Arts in 1893 and of Doctor of Laws in 1910. He invented, in 1886, the electrolytic process for the manufacture of aluminum now universally used. Two years later he commenced the commercial manufacture of aluminum with the Pittsburgh Reduction Company. His invention of the aluminum process was in litigation for some years, but he was ultimately conceded priority. His process was a potent factor in reducing the price of this metal, which was formerly as costly as silver.

He was a member of the American Philosophical Society and of the American Institute of Mining Engineers. He was awarded the Perkin Medal for his work in chemistry in 1911.

He was elected a member of the Institute in 1909.

He died on December 27, 1914.

Mr. Samuel Bancroft, Jr., Rockford, Wilmington, Del.

Mr. James R. Magee, 1720 Walnut Street, Philadelphia, Pa.

LIBRARY NOTES.

PURCHASES.

BLÜCHER, H.—Moderne technik: die wichtigsten Gebiete der Maschinentechnik. 2 volumes. 1912.

BÖCKLER, G. A.—Theatrum machinarum novum. 1686.

CLENNELL, J. E.—Cyanide Handbook. 1915.

DAVIES, JOHN P.—Engineering Office Systems and Methods. 1915.

DYER, F. L., and MARTIN, T. C.—Edison—His Life and Inventions. 2 volumes.

HAVEN, G. B., and SWETT, G. W.—Design of Steam Boilers and Pressure Vessels. 1915.

HOLDE, D.—Examination of Hydrocarbon Oils and Saponifiable Fats and Waxes. 1915.

HORSBURGH, E. M., ed.—Modern Instruments and Methods of Calculation. No date.

HOUSTON, A. C.—Studies in Water Supply. 1913.

HOVGAARD, W.—Structural Design of Warships. 1915.

LE BLANC, MAX.—Production of Chromium and its Compounds. 1904.

LEFFMANN, HENRY.—Examination of Water for Technical and Sanitary Purposes. 1915.

MELAN, J.—Plain and Reinforced Concrete Arches. 1915.

MORITZ, E. A.—Working Data for Irrigation Engineers. 1915.

NISSENSON, H.—Arrangement of Electrolytic Laboratories. 1905.

RICHARDSON, O. W.—Electron Theory of Matter. 1914.

RICHEY, A. S.—Electric Railway Handbook. 1915.

TAYLOR, W. W.—Chemistry of Colloids, and Some Technical Applications. 1915.

GIFTS.

Abrasive Material Company, Catalogue of Grinding Wheels. Philadelphia, no date. (From the Company.)

American Gas Institute, Proceedings, vol. ix, parts i and ii, 1914. New York, 1915.

American Institute of Electrical Engineers, Catalogue of the Wheeler Gift of Books, Pamphlets and Periodicals. New York, 1909. (From the Institute; second copy from Mr. Washington Devereux.)

American Institute of Mining Engineers, Transactions, vol. xlviii, 1914. New York, 1915. (From the Institute.)

American Iron and Steel Institute, Annual Statistical Report, 1913. Philadelphia, 1914. (From the Institute.)

American Society of Mechanical Engineers, Rules for the Construction of Stationary Boilers and for Allowable Working Pressures. New York, 1914. (From the Society.)

Atlantic Deeper Waterways Association, Proceedings of Seventh Annual Convention, 1914. New York, 1915. (From the Association.)

Bantam Anti-Friction Company, Official Blue Book of Ball and Roller Bearings. Bantam, Ohio, 1915. (From the Company.)

Bridgeport Brass Company, Hand Book for Architects, Engineers and Superintendents. Bridgeport, Conn., no date. (From the Company.)

Canada Department of Mines, Memoirs 65 and 66, Clay and Shale Deposits of the Western Provinces; Memoir 61, Moose Mountain District, Southern Alberta; Preliminary Report on the Bituminous Sands of Northern Alberta; Report, 1913; Bulletin No. 9, Investigation of the Peat Bogs, 1911–1912; Annual Report on the Mineral Production of Canada, 1913. Ottawa, 1914. (From the Department.)

Canada Geological Survey, Memoir No. 38, North American Cordillera, parts ii and iii. Ottawa, 1912. (From the Survey.)

Canadian Archives, A Guide to the Documents in the Manuscript Room at the Public Archives of Canada, vol. i. Ottawa, 1914. (From the Archivist.)

Celfor Tool Company, Catalogue No. 15 of High-speed Twist Drills and Internal Gear Drive Axles. Buchanan, Mich., no date. (From the Company.)

College of Physicians, Transactions, Third Series, vol. xxxvi. Philadelphia, 1914. (From the College.)

Commission of Fine Arts, Message from the President of the United States Transmitting the Report of the Commission, 1914. Washington, 1915. (From the Commission.)

Connecticut State Board of Health, Thirty-third Report, 1914. Hartford, 1915. (From the Board.)

Dake Engine Company, Catalogue of Steam and Air Motors and Pneumatic Hoists. Grand Haven, Mich., no date. (From the Company.)

Dobbie Foundry and Machine Company, Catalogue No. 18 of Derricks. Niagara Falls, N. Y., 1915. (From the Company.)

Drew Electric and Manufacturing Company, Catalogue No. 3 of Electric Railway, Light and Power Materials. Indianapolis, 1914. (From the Company.)

Florida State Railroad Commission, Eighteenth Annual Report. Tallahassee, 1915. (From the Commission.)

Franklin Printing Company, "Benjamin Franklin—Founder," The Remarkable Record of a Philadelphia Institution from 1728 to 1915. Philadelphia, 1915. (From the President of the Company.)

Gorton Machine Company, Catalogues Nos. 2-E and 2-B. Racine, Wis., 1915. (From the Company.)

Hartford Steam Boiler Inspection and Insurance Company, "The Locomotive," vol. xxvii. Hartford, Conn., 1908–1909. (From Mr. S. B. Adams.)

Hunter & Dickson Company, Catalogue No. 10 of Williams Steam Specialties. Cincinnati, 1915. (From the Company.)

Hydraulic Press Manufacturing Company, Catalogue No. 40 of Hydraulic Presses. Mount Gilead, Ohio, no date. (From the Company.)

Institution of Civil Engineers, Minutes of Proceedings, vol. cxcviii, part iv, 1913–1914. London, 1915. (From the Institution.)

K. Vitterhets Historie Och Antikvitets Akademien, Fornvannen. Stockholm, 1914. (From the Akademien.)

Leland Stanford Junior University, Register; Annual Report of the President, 1914. Stanford University, Cal., 1915. (From the University.)

Library of Congress, Washington Papers, Correspondence with the Officers, vols. i–iv, 1775–1784, and Index. Washington, 1915. (From the Library.)

Library of the Patent Office, Patent Office Library Series: No. 1, 3d edition. London, 1915. (From the Patent Office Library.)

Locomotive Stoker Company, Publications Nos. 11 and 12 of Instructions for Operating, Oiling and Maintaining Types B and C of the Street Locomotive Stoker. Schenectady, 1914. (From the Company.)

Maine Department of Labor and Industry, Report 1913–14. Waterville, 1915. (From the Department.)

Massachusetts Board of Education, Seventy-eighth Annual Report, 1913–1914. Boston, 1915. (From the Board.)

Minnesota Railroad and Warehouse Commission, Thirtieth Annual Report, 1914. Minneapolis, 1915. (From the Commission.)

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New York State Library, Ninety-fifth Annual Report, 1912. Albany, 1914. (From the Library.)

Northern Central Railway Company, Sixtieth Annual Report, 1914. Philadelphia, 1915. (From the Company.)

Ohio Industrial Commission, Report No. 3, Statistics of Mines and Quarries in Ohio, 1913. Columbus, 1915. (From the Commission.)

Ontario Department of Agriculture, Report, vols. i and ii, 1913; Report of Horticultural Societies, 1914. Toronto, 1915. (From the Department.)

Pennsylvania Commissioner of Banking, Report, Part i, 1914. Harrisburg, 1915. (From the State Librarian.)

Pennsylvania Railroad Company, Sixty-eighth Annual Report, 1914. Philadelphia, 1915. (From the Secretary.)

Pennsylvania Topographic and Geologic Survey, Report, 1913–14. Harrisburg, 1914. (From the State Librarian.)

Pittsburgh, Cincinnati, Chicago and St. Louis Railway Company, Twenty-fifth Annual Report. Pittsburgh, Pa., 1915. (From the Company.)

Rose Polytechnic Institute, April Bulletin. Terre Haute, Ind., 1915. (From the Institute.)

Steam Appliance Company, Catalogue No. 18 of Steam Specialties. Milwaukee, Wis., 1913. (From the Company.)

Syracuse University, University Number of Bulletin. Syracuse, N. Y., 1915. (From the University.)

Taunton Water Board, Report, 1914. Taunton, Mass., 1915. (From the Board.)

Thayer, M. Russell, "The Life, Character, and Writings of Francis Lieber." Philadelphia, 1873. (From Dr. Carl Hering.)

United States Army, Register. Washington, 1915. (From the Secretary of War.)

United States Coast and Geodetic Survey, Special Publication No. 24, Triangulation in Alabama and Mississippi. Washington, 1915. (From the Survey.)

United States Electrical Tool Company, Catalogue No. 12 of Portable Electrical Tools. Cincinnati, 1915. (From the Company.)

United States Navy, Register. Washington, 1915. (From the Secretary of the Navy.)

University of Colorado, Catalogue. Boulder, 1915. (From the University.)

University of North Dakota, General Catalogue. University, 1915. (From the University.)

University of Pennsylvania, Catalogue of University Lectures Delivered by Members of the Faculty in the Free Public Lecture Course, 1913–1914. Philadelphia, 1915. (From the University.)

University of Vermont, Catalogue. Burlington, 1915. (From the University.)

Ursinus College, Bulletin. Collegeville, 1915. (From the College.)

Veritys Limited, Catalogue of Electric Supplies, vol. ii. London, no date. (From the Company.)

Washington University, Catalogue. St. Louis, Mo., 1914. (From the University.)

Webster, Warren, & Company, Catalogue of Modulation System of Steam Heating. Camden, 1915. (From the Company.)

Weinman Pump Manufacturing Company, Catalogue of Steam and Power Pumping Machinery. Columbus, Ohio, no date. (From the Company.)

Whitman & Barnes Manufacturing Company, Catalogue No. 86 of Machinists' Supplies. Akron, Ohio, 1915. (From the Company.)

Wisconsin Geological and Natural History Survey, Mine Valuation and Assessment; Polyporaceæ of Wisconsin. Madison, 1914. (From the Survey.)

York Manufacturing Company, Ice Making and Refrigerating Data and Catalogue. York, Pa., no date. (From the Central Construction and Supply Company.)

PUBLICATIONS RECEIVED.

Explosives: Their Manufacture, Properties, Tests, and History, by Arthur Marshall, A.C.G.I., F.I.C., F.C.S., Chemical Inspector, Indian Ordnance Department. 624 pages, illustrations, 4to. Philadelphia, P. Blakiston's Son & Co., 1915. Price, $7 net.

Spencer Fullerton Baird: A Biography, including selections from his correspondence with Audubon, Agassiz, Dana, and others, by William Healey Dall, A.M., D.Sc. 462 pages, illustrations, plates, portraits, 8vo. Philadelphia and London, J. B. Lippincott Company, 1915. Price, $3.50 net.

Electrical Instruments in Theory and Practice, by W. H. F. Murdoch and U. A. Oschwald. 366 pages, illustrations, 12mo. London, Whittaker & Co., 1915. Price, 10s.6d. net.

Canada, Department of Mines: Summary Report of the Mines Branch for the Calendar Year Ending December 31, 1913. 214 pages, illustrations, tables, plates, maps, 8vo. Annual Report on the Mineral Production of Canada During the Calendar Year 1913, by John A. McLeish, B.A., Chief of the Division of Mineral Resources and Statistics. 363 pages, 8vo. Preliminary Report on the Bituminous Sands of Northern Alberta, by S. C. Ells. 92 pages, illustrations, plates, maps, 8vo. Investigation of the Peat Bogs and Peat Industry, by A. v. Anrep. 47 pages, illustrations, plates, tables, maps, 8vo. Preliminary Report on the Mineral Production of Canada During the Calendar Year 1914, prepared by John McLeish, B.A., Chief of the Division of Mineral Resources and Statistics. 24 pages, 8vo. Ottawa, Government Printing Bureau, 1914 and 1915.

U. S. Bureau of Mines: Bulletin 80, A Primer on Explosives for Metal Miners and Quarrymen, by Charles E. Munroe and Clarence Hall. 125 pages, illustrations, plates, 8vo. Bulletin 81, The Smelting of Copper Ores in the Electric Furnace, by Dorsey A. Lyon and Robert M. Keeney. 80 pages, illustrations, 8vo. Bulletin 87, Houses for Mining Towns, by Joseph H. White. 64 pages, illustrations, plates, 8vo. Bulletin 88, The Condensation of Gasoline from Natural Gas, by George A. Burrell, Frank M. Seibert and G. G. Oberfell. 106 pages, illustrations, plates, 8vo. Technical Paper 81, The Vapor Pressure of Arsenic Trioxide, by H. V. Welch and L. H. Duschak. 20 pages, illustrations, plate, 8vo. Technical Paper 89, Coal-tar Products and the Possibility of Increasing their Manufacture in the United States, by Horace C. Porter, with a chapter on Coal-tar Products Used in Explosives, by C. G. Storm. 21 pages, 8vo. Technical Paper 90, Metallurgical Treatment of the Low-grade and Complex Ores of Utah, a preliminary report by D. A. Lyon, R. H. Bradford, S. S. Arentz, O. C. Ralston, and C. L. Larson. 39 pages, 8vo.

Harrison Safety Boiler Works, Cochrane Engineering Leaflet No. 18, Testing V-notch Meters. 48 pages, illustrations, 8vo. Philadelphia, Harrison Safety Boiler Works, 1915.

North Pole Aftermath, speech by Hon. S. D. Fess, of Ohio, in the House of Representatives, Congress of the United States, Thursday, March 4, 1915. 27 pages, 8vo. No place, no date.

U. S. Department of Agriculture, Bulletin 210, Seed Production of Western White Pine, by Raphael Zon, Chief of Forest Investigations. 15 pages, 8vo. Washington, Government Printing Office, 1915.

Great Men and How They are Produced, by Caspar L. Redfield. 32 pages, 8vo. Chicago, Author, 1915. Price, 15 cents.

CURRENT TOPICS.

Production of Explosives in the United States in 1913. A. H. FAY. (*Tech. Paper No. 85, U. S. Bureau of Mines,* 1914.)—The total production of explosives in the United States in 1913 was 463,514,881 pounds, a decrease of 25,878,250 pounds from the production in 1912. The production of black powder amounted to 194,146,747 pounds, permissible explosives 27,685,770 pounds, and other high explosives 241,682,364 pounds. In the coal mines of the United States 209,352,938 pounds of explosives were used in 1913 to produce 570,048,125 tons of coal; this is an increased production from 2.36 to 2.72 tons of coal per one pound of explosive over 1912. The use of permissible explosives in coal mines continues to increase.

Melting Metal Wires into Quartz-glass Vessels. R. SHALLER. (*Zeitschr. Instrumentenk. Beib.,* xii, 130.)—It is often desired to attach ordinary glass, capable of being worked in the usual furnaces, to quartz glass which requires special treatment, particularly when only a small portion of a large and complicated vessel needs to be made of the latter variety. Owing to the exceptionally small coefficient of expansion and the high melting-point of quartz glass, the immediate attachment to it of ordinary glass and the direct melting-in of platinum wire are impossible. The junction can be accomplished only by a series of glasses with a gradual transition of qualities. These require special working: the nearer the qualities of quartz glass being approached, the hotter has to be the temperature of the blast flame, and either the oxyhydrogen or the oxy-coal gas flame must be employed. Platinum on account of its chemical properties, is convenient for leading-in wires, but, as its coefficient of expansion is relatively high, a large number of transition glasses are needed. In this respect tungsten and molybdenum are preferable; their cubical expansion coefficients are 130×10^{-7} and 150×10^{-7}, and they can therefore easily be melted into glass whose coefficient is between 100 to 170×10^{-7}. Iron-nickel alloys, which have a very low coefficient of expansion, do not give safe, gas-tight joints, because the coefficient admittedly increases rapidly with rising temperature.

Units of Weight and Measure. (*Bureau of Standards,* Circular No. xlvii, Washington, 1914.)—This circular is to supersede the Bureau of Standards Miscellaneous Publication on "Tables of Equivalents of the U. S. Customary and Metric Weights and Measures," and contains an extensive series of tables. The units

are defined and their interrelation shown in tables, and tables are also given of equivalents from 1 to 999 units. Some special tables are appended, such as: Millimetres and decimal and binary fractions of an inch; hundredths of an inch to millimetres, and *vice versa;* comparisons of various pounds and tons in use in the United States; comparison of prices (French, German, English, and United States).

Radium as a Lightning Conductor. B. SZILARD. (*Soc. Int. Elect.*, Bull. iv, 669.)—The ordinary point-lightning conductor is discussed from an efficiency standpoint and its limitations are explained. The author then proposes an ionization method for preventing electric storms by means of radium, disclaiming originality, however, by a reference to Arago in which flames were used with the same object. We now know that the flames would ionize the atmosphere; the radium, however, would exert other influences in addition to ionization towards the same end. A considerable section of this paper is then devoted to an exposition of the influence of radium emanations upon the electrical conductivity of air. Following this comes a theoretical discussion of the effects which would follow if an ordinary lightning conductor were furnished with a radium-covered screen placed beneath the point. The net results would seem to be a progressive conductivity of the air towards the point, which would promote the electrical flow in this direction. A detailed description next follows of a radium-furnished instrument for the practical study of the subject The apparatus was provided with a suitable installation for the quantitative examination of the phenomena observed. The whole scheme was specially designed for easy portability. The results obtained are well explained and illustrated by a series of comparison curves. The author believes that work on these lines merits further investigation.

Lag in Marine Barometers on Land and Sea. C. CHREE. (*Meteorologist Office,* Geophys. Mem. viii, 173.)—The marine barometer is a so-called "Kew Pattern" barometer, in which a portion of the tube is specially constricted in order to introduce great resistance to rapid motion of the mercury and so enable accurate pressure readings to be made on board ship even when the sea is very rough when an ordinary mercury barometer cannot be read with accuracy on account of "pumping" of the column of mercury. The "Kew Pattern" barometer is one in which the capacity correction is allowed for by suitable gradation of the scale in "apparent" inches, not true inches.

In 1880 Stokes discussed the theory of the sluggishness of the marine barometer and found that when pressure is changing uniformly the reading of the barometer should be the same as the true reading L minutes previously where L is the "lagging time" of the instrument, and is equal to $0.91 \times$ time taken by the mercury to fall the inch from $1\frac{1}{2}$ to $\frac{1}{2}$ inch above the true level of the

barometer at the time. This result does not depend upon the rate at which pressure is changing.

From experiments made at Kew Observatory with two marine barometers it is shown that, in fact, the effect of lag is much greater than according to Stokes's formula, and that it depends partly upon the rate at which the pressure is changing. Thus the ratio of the observed to the calculated lagging-time varies from 10 or 12 when the rate of pressure-change per hour is 0.0058 inch to 5 or 6 when the rate is 0.0242 inch per hour. On the other hand, readings made at sea on board the steamship *Hesperian* with the same two barometers appear to indicate that on board ship the effect of lag is exceedingly small, even smaller than it should be according to Stokes's formula.

Characteristic Equations of Tungsten Filament Lamps and Their Application in Heterochromatic Photometry. G. W. MEDDLEKAUFF and J. F. SKOGLAND. (*Am. Illum. Eng. Soc. Trans.*, ix, 734.)—This paper gives an account of the difficulties experienced at the Bureau of Standards in calibrating lamps differing in color from the 4-watt-per-candle carbon primary standards which maintain the international candle. Comparison of lamps of the same color involves no special difficulties, but when a color difference exists there is a want of agreement in the results obtained by experienced observers, due principally to two causes: (*a*) Difference in color vision; (*b*) difference in judgment of intensity. Hence to establish standards it is not only necessary to have observers of normal color vision, but also to obtain a very large number of readings by experienced observers. In the photometry of different colored lights the only methods which are sufficiently sensitive are: (1) Flicker, (2) equality of brightness. At the Bureau of Standards more consistent results have been obtained by using (2). The method proposed by the authors for surmounting the various difficulties consists in using tungsten secondary standards, which can be adjusted to a color match with all incandescent lamps and approximately with flame lamps. These are measured at a match in color directly in terms of the primary standards, and their candle-powers are determined from the corresponding measured voltages. This is done by the use of characteristic equations which the authors have derived from the results of measurements of tungsten lamps of various sizes and makes. In determining these equations the difficulties due to color difference are dealt with once for all. Tables of values computed by means of these equations are given for use in practical photometry. In the discussion, F. E. Cady emphasized the fact that the method does not eliminate the color difference in photometry, but merely localizes it in one place. P. G. Nutting suggests other methods of overcoming the color difficulty. The authors, in reply, pointed out that the color-difference difficulties are encountered once for all, and it is immaterial as to whether it is

done by means of an equality-of-brightness or a flicker photometer. The only effect resulting from a possible difference in value obtained by the use of the flicker photometer would be a slight change in the constants of the equations. In the National Physical Laboratory the step from the carbon standards is made by the cascade method, while at the Bureau of Standards it is made by the use of two calibrated blue glass screens of practically the same transmission coefficient.

The Transverse Testing of Cast Iron. G. HAILSTONE. (*Iron and Steel Inst. J.*, xc, 82.)—The author describes a special machine which has been designed for making transverse tests on cast-iron bars of different dimensions. A series of tests has been made on a range of mixtures from weak to strong cast irons using test-bars 2×1 inch in section tested on 36-inch centres and 1-inch square bars tested on 12-inch centres. The results show that the ratio of the strengths is 1.153 for machined bars and 1.146 for bars tested with the skin on, instead of 1.333 as originally allowed for in the standard English specifications. The best standard test-bar, giving the most consistent and comparable results, is the one cast to $2\frac{1}{8} \times 1\frac{1}{8}$ inches in section and 42 inches in length and machined to 2×1 inch and tested on 36-inch centres. The rate of loading should not exceed one hundredweight in 15 seconds, this being a very convenient rate.

Spectra of Magnesium, Calcium, and Sodium Vapors. J. BARNES. (*Astrophys. Journ.*, xxxix, 370.)—Further experiments on the spectra of metallic vapors under the conditions given by an electrically-heated furnace, the metals being vaporized *in vacuo*. In magnesium one of the chief features is the strength of the line λ 4571, compared with its absence or weakness under other conditions. It is a well-marked sun-spot line. For calcium the chief affected line is 6573, which is noted by Hale and Adams to be one of the most strongly affected lines on the whole of the spot spectrum. The sodium lines in the furnace spectrum are very much intensified, with wings very wide and clear, just as is noted in these lines in sun-spot spectra. These observations suggest that the experimental conditions reproduced very nearly the physical conditions of density, temperature, and excitation which may exist in sun-spot vapors.

The Color of Illuminants. L. A. JONES. (*Am. Illum. Eng. Soc. Trans.*, ix, 687.)—Color analysis of the light emitted by various sources may be made by (*a*) the trichromatic or (*b*) the monochromatic method. The author has made a series of determinations by method (*b*), using the well-known Nutting colorimeter. He takes the light from the noon sun reflected from a block of magnesium carbonate as his standard of white light. The monochromatic light was obtained by means of a constant-deviation prism; the wave-

length of this light can be adjusted by rotating a drum which is graduated in wave-lengths. Tables are given showing the values of the "per cent. white" and dominant hue for a large number of sources. In the case of glow lamps color analyses are made from the point at which the filament is just glowing up to the maximum current. The candle-power and the watts per candle are measured over the whole range. The precision obtainable in a single reading is of the order + 3 per cent. in the "per cent. white" reading, and + 0.5 $\mu\mu$ in the wave-length of a dominant hue. The author claims that this method offers a means of specifying the efficiency of a lamp in absolute terms, free from any arbitrary factors, such as color screens and filters. In the discussion H. E. Ives pointed out that for precision work (1) there must be a standard of white light; (2) we must be able to reproduce that white light at any time or place; (3) we must have some authorized method of measuring the brightness of the spectrum color against the white. He himself had previously suggested noon sunlight. He also referred to an instrument by which any spectrum energy-distribution, such as white light, can be produced at will, and to the difficulty of measuring the intensity of a white against a pure spectrum color. The author, in his reply, stated that color analyses of the acetylene flame have been made over a long period of time, using noon sun as a standard white, but no appreciable variation in the analyses has been found.

Standard Specifications for Cement. (*Year Book of Amer. Soc. Testing Materials,* 1914, 290.)—*General Conditions.*—All cement shall be inspected and at least twelve days allowed for inspection and testing. A bag of cement shall contain 94 pounds of cement net; and each barrel of Portland cement shall contain four and of natural cement three bags of above net weight. Cement failing to meet the seven-day requirements may be held pending the results of the twenty-eight-day tests before rejection. All tests shall be made in accordance with the methods of the American Society of Civil Engineers. Acceptance or rejection shall be based on the following requirements:

Natural cement is defined as the finely-pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to expel the carbonic acid gas. *Fineness.*—Not more than ten per cent. by weight to be left on a No. 100 and not more than thirty per cent. on a No. 200 sieve. *Time of Setting.*—At least ten minutes for initial set and from thirty minutes to three hours for hard set. *Tensile Strength.*—The minimum requirements for briquettes one square inch in cross-section are given in the table: no retrogression in strength must be shown within the periods specified. *Constancy of Volume.*—Pats of neat cement about three inches in diameter, 0.5 inch thick in centre, and tapering to a thin

edge, shall be kept in moist air for twenty-four hours, and subsequently shall remain firm and hard and show no signs of distortion, checking, cracking, or disintegration when kept in air at normal temperature or in water at about 70° F. (21° C.) for at least twenty-eight days.

Portland cement is defined as the finely-pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly-proportioned argillaceous and calcareous materials, and to which no addition greater than three per cent. has been made subsequent to calcination. *Specific Gravity.*—Not less than 3.10. If a sample fails to pass, a second test may be made on a sample ignited at a low red heat: the loss in weight on ignition shall not exceed four per cent. *Fineness.*—Not more than eight per cent. on a No. 100 and not more than twenty-five per cent. on a No. 200 sieve. *Time of Setting.*—At least thirty minutes for initial set and from one to ten hours for hard set. *Tensile Strength.*—See table: same conditions as for natural cement. *Constancy of Volume.*—Same as for natural cement, with the addition that a third pat is exposed in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours. *Sulphuric Acid and Magnesia.*—Not more than 1.75 per cent. SO_3 and not more than four per cent. MgO.

Age	Tensile strength of			
	Natural cement		Portland cement	
	Neat	Mixed with 3 parts of standard Ottawa sand	Neat	Mixed with 3 parts of standard Ottawa sand
	Pounds	*Pounds*	*Pounds*	*Pounds*
24 hours in moist air	75	...	175	...
7 days (1 in moist air, 6 in water)	150	50	500	200
28 days (1 in moist air, 27 in water)	250	125	600	275

Felspar as a Possible Source of American Potash. A. S. CUSHMAN and G. W. COGGESHALL. (*Amer. Inst. Chem. Eng.*, Dec. 2, 1914.)—In 1914 the United States of America imported potassium salts to the value of $15,000,000, including chloride of the value of $8,000,000. Most of this, including 85 per cent. of the chloride, was utilized in the fertilizing industry, and the remainder of the chloride was converted chiefly into hydroxide, carbonate, chlorate, and bichromate. Most of the American sources of potash, namely, the kelps, saline lakes and wells, and alunite deposits, are situated in the West, whereas the demand exists east of the Allegheny Mountains; and it is considered unlikely that the Panama Canal will enable Western potashes to compete with the European product. On the other hand, the great Appalachian felspar dikes are close to the centres of demand. In the process described, a

mixture of ground felspar, 10 per cent. K_2O, and burnt limestone is formed into "clumps" by treatment with calcium chloride solution and heated in a rotary kiln, the fuel being oil or powdered coal. The red-hot product falls into lixiviating vats. The weaker vat liquors are used in a further operation, while the stronger ones are concentrated by spraying through the waste hot gases, whereby loss of potassium chloride by volatilization is also prevented. The product, after drying in a rotary drier which utilizes the hot waste gases of the limekiln, contains 70 to 80 per cent. KCl, 14 to 16 per cent. NaCl, and small amounts of calcium salts and moisture, as against 70 to 80 per cent. KCl in the imported "80 per cent. muriate." A high-grade product can be obtained by fractional crystallization. The general plant, in the main, resembles a Portland cement mill. The total cost of a plant to handle 300 tons of felspar per twenty-four hours is given at $100,000 for the general plant, with an additional $70,000 for the special equipment. The estimated total expenditure per day of $1488.90 is composed of $800 for raw materials, $554.60 for manufacturing operations, and $64.30 for charges, including interest and depreciation. Calculating on the basis of an 80 per cent. conversion of K_2O to KCl, the cost of the product amounts to $31.32 per ton, as against $37.50 for the normal price of the imported "80 per cent. muriate," which latter, however, is probably artificially controlled. No account is taken in these estimates of possible valuable by-products. Since all the requisite materials are available in this country, the authors consider that the United States of America might be rendered independent of foreign supplies.

Presence of Salt an Indication of Other Impurities in Boiler Water. (*Electr. World,* lxv, No. 2, 101.)—At one of the large generating stations in New York City, where salt water is employed to cool the condensers, the condensate is tested every hour to determine whether any salt is present. If any is found, it indicates that the condensers are leaking and must be immediately attended to or all of the boiler water will be contaminated. The test is also valuable in that it forewarns when additional feed-water compound may be required to precipitate impurities which are carried into the boilers along with the salt. Not only is the condensate tested, but also the boiler's contents. This, however, is done only once a day, as leakage of scale-forming compounds into the feed-water system is usually noted by the analysis of water from the condensers. The standard titration test of adding silver nitrate to the water is employed. This is much simpler than testing for the presence of other impurities. To remove scale-forming impurities from the water it is treated by the addition of sodium carbonate, and the precipitate is removed by blowing off the boilers when the fires are banked.

Chemiluminescence. S. MOELLER. (*Archiv. Pharm. Chem.*, xxi, 440.)—The appearance of light has been noted in several chemical reactions, notably in that of Grignard, when an ether solution of an alkyl halide reacts with magnesium dust. A red light is developed on mixing 35 c.c. of each of the following solutions: A 1:2 potassium carbonate solution, a 1:10 pyrogallol solution, and a 35:100 formaldehyde solution; then adding 50 c.c. of 30:100 hydrogen peroxide solution. Also phenylmagnesium bromide, in ether solution, develops an intense green light on contact with moist air. The effect is not, however, due to the moisture, but to oxidation. The luminescence is stronger in an atmosphere of pure oxygen than in other gases. Ether which has stood months over calcium chloride reacts well; some, but not all, specimens of official ether do so also. Chemiluminescence is observed with most organic magnesium compounds, and its intensity is directly proportional to the molecular weight of the halogen derivative.

Action of Acid Mine Water on the Insulation of Electric Conductors. H. H. CLARK and L. C. ILSLEY. (*U. S. Bureau of Mines, Techn. Paper 58.*)—Four different types of insulation were used in the tests: (1) Wire, 0.162 inch diameter, covered with eight layers of varnished cotton cambric, 0.146 inch thick, and one layer of cotton braid, 0.056 inch thick, saturated with a composition. (2) Wire, 0.325 inch diameter; rubber layer, 0.0925 inch thick, containing 30 per cent. Para; cotton tape, single layer; cotton braid, with waterproof finish, two layers, 0.035 and 0.033 inch thick. (3) Wire, 0.162 inch diameter; varnished cambric, 11 layers, 0.116 inch thick; cotton braid with weatherproof finish, two layers, 0.029 and 0.04 inch thick. (4) Lead-sheathed telephone cable, composed of five pairs of paper-covered wires, surrounded by lead 3/32 inch thick. The cables were sprinkled with 0.45 per cent. sulphuric acid or a 1.2 per cent. solution of ferrous sulphate in this acid three times daily for the first four weeks, once daily for ten weeks, twice daily for seventy-six weeks, and subsequently once daily, and, beginning eight months after the tests were started, the insulation resistance was measured at intervals over a period of two years. The rubber insulation showed no apparent deterioration, and the insulation resistance, although only about half the original, was still very good. The telephone cable also gave good results. The cambric-covered wires, (1) and (3), had practically lost their insulation, mainly through the penetration of the liquid between the layers.

Steel Coated with Copper. W. M. PAGE. (*U. S. Patent 1,125,158 of 1915.*)—Steel articles are provided with a coherent coating of magnetic iron oxide and are then dipped into molten copper until bubbling ceases.

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